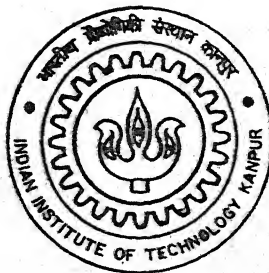


# Feature Based Design for Injection Molding

By

**Deepak Arzare**



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**DEPARTMENT OF MECHANICAL ENGINEERING**

**Indian Institute of Technology Kanpur**

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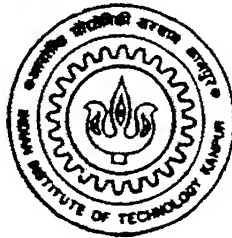
# **Feature Based Design for Injection Molding**

A Thesis Submitted  
in Partial Fulfillment of the Requirements  
for the Degree of

**Master of Technology**

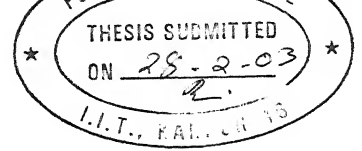
by

**Deepak Arzare**



**Department of Mechanical Engineering  
INDIAN INSTITUTE OF TECHNOLOGY KANPUR**

Feb, 2003



## CERTIFICATE

It is certified that the work contained in the thesis entitled “***Feature Based Design for Injection Molded Parts***”, by ***Mr. Deepak Kumar Arzare*** (Roll. No. Y110506) has been carried out under our supervision and that this work has not been submitted elsewhere for a degree.

Dr. N.V.Reddy  
Asst. Professor  
Department of Mechanical Engg.  
Indian Institute of Technology Kanpur

Prof. KripaShankar  
Professor  
Department of Ind. & Mgt. Engg.  
Indian Institute of Technology Kanpur

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भारतीय प्रौद्योगिकी संस्थान कानपुर  
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Dedicated  
To  
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# Acknowledgements

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First I offer my pranam to God Shri Shirdi Sai Baba and my guru Shri Saiyad Saheb, for every door of opportunity they have opened for me throughout my life and always putting me up at successful end.

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Deepak Arzare

## **Abstract**

In recent years, the concept of concurrent engineering has been proposed to reduce the product development time and involved cost. It suggests to consider product, process and all life cycle issues, through all the phases of development cycle. Conventional computer based design tools are not suitable for concurrent engineering due to lack of capability to support interactive decision making and heavy involvement of designer's expertise. Thus there is big need to develop object oriented product design systems.

The use of product features as modeling primitives, with in-built heuristic process knowledge makes the design system much more efficient, easy to use and versatile. Such 'feature based modeling' environment also overcomes the need of complex feature extraction and feature mapping algorithms, facilitating easy and quick data transfer for downstream CAD/CAM application.

The present work is an attempt towards the development of a feature-based design system for 'Injection Molding' using predefined 3D part features as design primitives. The system has its own modeling and rendering environment with the expert knowledge to warn and guide the user. Product geometry plays a very important role for injection molding and many times is the cause of defected moldings. Product geometry related standard guidelines and heuristic knowledge is translated in to expert knowledge base of the developed system.

The platform is built in 'C' on Linux with OpenGL support for graphical environment. GLUT libraries are used for modeling and GLUI libraries for graphical user interface (GUI).

# Table of Contents

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List of Figures

List of Tables

<b>1. Introduction and Literature Survey</b>	<b>1</b>
1.1 Injection Molding	1
1.1.1 Molding Cycle	3
1.1.2 Tooling Cost	4
1.2 Design for Injection Molding (DFIM)	4
1.3 Object Oriented Product Design	6
1.4 Design with Features	7
1.5 Knowledge Based Systems	9
1.6 Integration of KBE and CAD	10
1.7 Literature Review	11
1.8 Objective and Scope of the Work	15
1.9 Organization of the thesis	16
<b>2. Feature Based Modeling</b>	<b>17</b>
2.1 Application of form features in CAD/CAM	17
2.1.1 Feature Recognition	18
2.1.2 Feature Mapping	18
2.1.3 Feature Based Design	19
2.2 Design by Feature Approaches	21
Destructive Modelling	
Synthesis	
Dynamic Editing	
2.3 Feature Construction	25
2.4 Injection Molded Part Features	26
2.4.1 Feature/ Function Data for Plastic Molded Parts	27
2.4.2 Most Common Features	33
<b>3. Design Rules for Injection Molding</b>	<b>35</b>
3.1 Basic Process Factors in Injection Molding	35
3.2 Faults in IM components	36

3.3 Rejection Rates	37
3.4 Product Geometry	37
3.5 Design Guidelines for Injection Molding	38
3.5.1 Wall Thickness	
3.5.1 Part Feature Guidelines	38
3.5.2.1 Wall thickness Design	42
3.5.2.2 Holes and Depression Design	44
3.5.2.3 Rib Design	46
3.5.2.4 Boss Design	48
3.5.2.5 Boss as Fastener Design	50
3.5.2.6 Radii, Filet and Corner Design	50
3.5.2.7 Gusset Design	52
3.5.2.8 Parting Line and Ejection Design	53
3.5.2.9 Better Appearance Design	54
3.6 Implemented Expert Database	56
<b>4. System Design and Implementation</b>	<b>57</b>
4.1 Geometric Modeling	57
4.1.1 Analytical vs. Approximating Techniques	58
4.1.2 Vector vs. Raster Data	58
4.1.3 Geometrical Dimensionality	59
4.1.4 Topological Dimensionality	60
4.2 Modelling of solid objects	61
4.3 Implemented Modelling Scheme	67
4.4 System Design Architecture	67
4.4.1. Data Structures	67
4.5 Software Features	70
4.6 Case Study	75
<b>5. Conclusion and Future Scope</b>	<b>80</b>
5.1 Conclusion	80
5.2 Scope for the Future Work	80
<b>Bibliography</b>	<b>82</b>

# List of Figures

---

<b>Fig. 1.1</b>	Injection Molding Machine	2
<b>Fig. 1.2</b>	Injection Molding Cycle	3
<b>Fig. 1.3</b>	Conventional Design Approach in Injection Molding	5
<b>Fig. 1.4</b>	The Concurrent Engineering Approach	5
<b>Fig. 1.5</b>	The Design for Injection Molding Approach	6
<b>Fig. 1.6</b>	Architecture of Design with Features	8
<b>Fig. 2.1</b>	Feature Based Design System for Injection Molding	21
<b>Fig. 2.2</b>	Feature Construction by Boolean Operations	23
<b>Fig. 2.3</b>	Structure of Feature Based Design System with Dynamic Editing	24
<b>Fig. 2.4</b>	The Features of a Plastic Stool	33
<b>Fig. 3.1</b>	Poor Geometry Resulting in Defects	36
<b>Fig. 3.2</b>	Stiffness v/s Wall Thickness	39
<b>Fig. 3.3</b>	Flow Length Variation with Wall Thickness	40
<b>Fig. 3.4</b>	Cooling Time Variation with Wall Thickness	41
<b>Fig. 3.5</b>	Temperature History of Molding Cycle	41
<b>Fig. 3.6</b>	Wall Thickness Transition	42
<b>Fig. 3.7</b>	Use of Land	44
<b>Fig. 3.8</b>	Hole Proportionate Dimensions	44
<b>Fig. 3.9</b>	Use of Ribs	46
<b>Fig. 3.10</b>	Ribs Proportionate Dimensions	47
<b>Fig. 3.11</b>	Boss Supported by Ribs	48
<b>Fig. 3.12</b>	Use of Generous Radius	50
<b>Fig. 3.13</b>	Effect of Radius on Stress Concentration	51
<b>Fig. 3.14</b>	Use of Gussets to Avoid Warpage	52
<b>Fig. 4.1</b>	Object representation methods	60
<b>Fig. 4.2</b>	Cell Decomposition	62
<b>Fig. 4.3</b>	Octree Encoding	63
<b>Fig. 4.4</b>	Models Generated by Sweep	64
<b>Fig. 4.5</b>	Primitive Instancing	65
<b>Fig. 4.6</b>	The CSG model	66
<b>Fig. 4.7</b>	Modeler Structure	67

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<b>Fig. 4.8</b>	Software Main Window	<b>70</b>
<b>Fig. 4.9</b>	Side Control Panel	<b>71</b>
<b>Fig. 4.10</b>	Bottom Control Panel	<b>71</b>
<b>Fig. 4.11</b>	Design Options	<b>72</b>
<b>Fig. 4.12</b>	Features Available in Library	<b>72</b>
<b>Fig. 4.13</b>	Light Enable Menus	<b>73</b>
<b>Fig. 4.14</b>	Wire Frame and Scale Menus	<b>73</b>
<b>Fig. 4.15</b>	Common Options	<b>74</b>
<b>Fig. 4.16</b>	Guidelines Manual	<b>74</b>
<b>Fig. 4.17</b>	Guideline Manual	<b>75</b>
<b>Fig. 4.18</b>	Boss Guidelines Window	<b>75</b>
<b>Fig. 4.19</b>	Displayed Plate Feature	<b>76</b>
<b>Fig. 4.20</b>	Displayed Plate Feature with online Guidance	<b>76</b>
<b>Fig. 4.21</b>	Displayed Hole Feature as material to be removed	<b>77</b>
<b>Fig. 4.22</b>	Displayed Gusset Feature	<b>77</b>
<b>Fig. 4.23</b>	Ring Feature	<b>78</b>
<b>Fig. 4.24</b>	Boss Feature with Guidelines	<b>78</b>
<b>Fig. 4.25</b>	3D Rendering of Features for Plastic Part	<b>79</b>

# List of Tables

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<b>Table 1.1</b>	Features Found in Study	<b>26</b>
<b>Table 1.2</b>	Functions Found in Study	<b>27</b>

# Chapter 1

## Introduction

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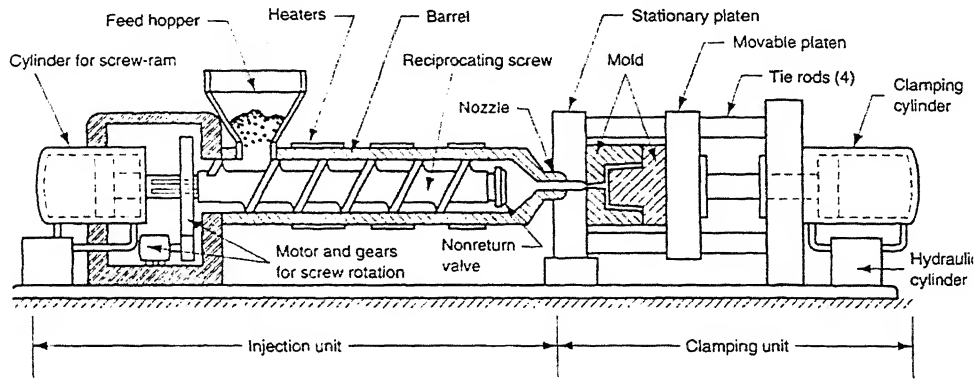
Hardly a product on the market today does not have some component made of polymer. Polymers are long chain molecules, also called macromolecules, which are formed by polymerization, that is, by linking and cross-linking of different monomers [Kalpakjian and Serope, 1995]. Although the word plastic is commonly used synonym for the polymers, plastics are one of the polymeric materials and have extremely large molecules.

Consumer and industrial products made of plastics include food and beverage containers, packaging, signs, house-wares, textiles, medical devices, foams, paints, safety sheets, toys, appliances, lenses, gears, electronic and electrical products, automobile bodies and components. Because of their many unique and diverse properties, plastics have increasingly replaced metallic components such as automobile, civilian and military aircraft etc. These substitutions reflect the advantage of plastics in terms of high strength to weight ratio, design possibilities, wide choice of colors and transparencies, ease of manufacturing and relatively low cost. Plastic is not just used because of lightweight properties but they are being modified enough to replace metallic applications. These make plastics a new era material.

### 1.1 Injection Molding

Injection molding (IM) is one of the most versatile (about 70%) production methods in the plastic manufacturing industries [Rosato and Rosato, 2000]. It is a process that is capable of producing molded parts of relatively intricate configuration with good dimensional accuracy. Commonly, powdered or granular thermoplasts are used as raw material but thermosetting powdered materials are also being injection molded.

In this process, the solid molding material fed to the machine is heated, melted and then forced under pressure in to the mold of designed configuration. In the mold, it cools and hardens and gets ejected to make the mold ready for next cycle.



**Fig 1.1-Injection Molding Machine**

As illustrated in Fig. 1.1, injection molding machine consists of two principal components:

- Plastic injection unit
- Mold clamping unit

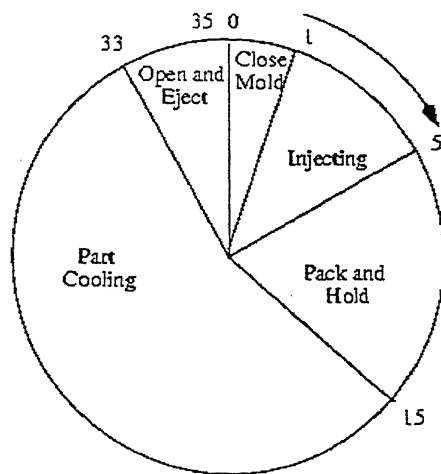
The injection unit is much like an extruder. It consists of a barrel that is fed from one end by a hopper containing a supply of plastic pellets. Inside the barrel is a screw whose operation surpasses that of an extruder screw in the following respect: in addition to turning for mixing and heating the polymer, it also acts as a ram that rapidly moves forward to inject molten plastic in to the mold. A non-return valve mounted near the tip of the screw prevents the melt from flowing backward along the screw thread. Later in the molding cycle the ram retracts to its former position. Because of its dual action, it is called the reciprocating screw; the name also identifies the machine type. Older injection molding machines uses a simple ram (without screw flights) but the superiority of the reciprocating screw design has led to its widespread adoption in today's molding plant.

The clamping unit is concerned with the operation of the mold. Its functions are to 1) hold the two halves of the mold in proper alignment with each other, 2) keep the mold

during injection by applying a clamping force sufficient to resist the injection force, 3) open and close the mold at the appropriate times in the molding cycle. The clamping unit consists of two platens, a fixed platen and a movable platen, and a mechanism for translating the latter. The mechanism is basically a power press that is operated by a hydraulic piston or mechanical toggle devices of various types [Mikell P and Groover, 1996]. Clamping forces of several thousand tons are available on large machines.

The Advantages of Injection Molding are, high production rates, design flexibility, repeatability within tolerances and relatively low labor required. The disadvantages are initial equipment investment and tooling (mold) costs are quite high and part must be designed for effective molding.

### 1.1.1 Molding Cycle



**Fig 1.2-Injection Molding Cycle**

The cycle for injection molding of a thermoplastic polymer proceeds in the following sequence, illustrated in Figure 1.2.

- Starting with an empty cylinder, granular material from the feed hopper falls on the rear flights of the screw, which rotates, carrying material to the front of the cylinder. During its passes along the cylinder, it is plasticized to a fluid state.
- The mold closes and the cylinder moves forward on its carriage until the nozzle is in contact with the entrance to the mold

- The hydraulic cylinder at the rear of the machine moves the screw forward and the injection take place. The plastic cools and begins to solidify when it encounters the cold surface of the mold. Ram pressure is maintained to pack additional melt in to the cavity to compensate for contraction during cooling.
- After a short interval (holding time) the screw is rotated and retracted with the nonreturn valve open to permit fresh melt to flow in to the forward portion of the barrel. This melt is ready for the next shot. Meanwhile the plastic in the mold has completely solidified.
- The mold opens, the molding is ejected and the mold closes again, ready for the next cycle.

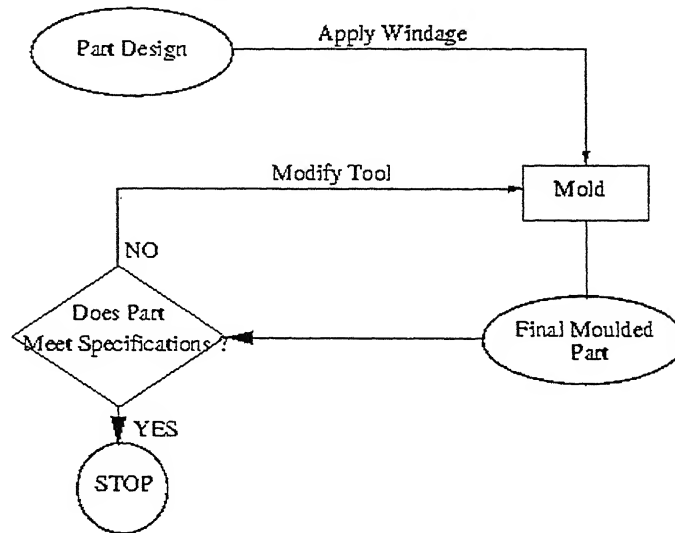
### **1.1.2 Tooling Cost**

The current, empirical approach to design of IM parts is "make it and break it." The mold is manufactured; part is molded, and checked for the performance or defects. The mold design is modified and this is repeated until a flawless part of required specification is obtained. The very high cost of molds and these iterations make the product development cost very high. Major efforts are being expended to put science and engineering in IM design rather than relying on trial and error. Thus the end goal of any plastic industry is to optimize the mold development cost which yields to economic and competitive products. This Design for Injection Molding (DFIM) methodology has become an important part of integrated product design system.

## **1.2 Design for Injection Molding (DFIM)**

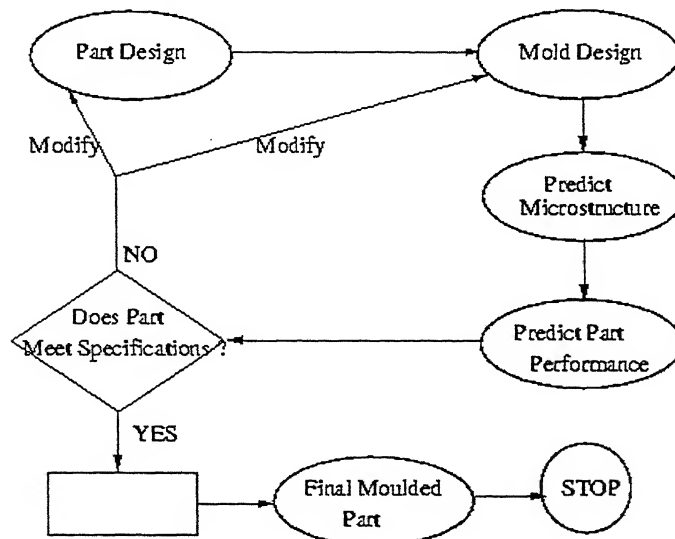
As discussed, the conventional approach to product mold design for injection molding is based on allowances for post mold shrinkage of the part. Experienced designers account for possible warping by allowing the allowances also (known as 'windage' molding language) in tool design (Figure 1.3). The part is subsequently molded and examined to check whether it meets specifications or flawless. This involves

modification of the existing mold repetitively until the part is within specifications and results in expensive product development time and involved cost.



**Fig. 1.3 -Conventional Design Approach in Injection Molding**

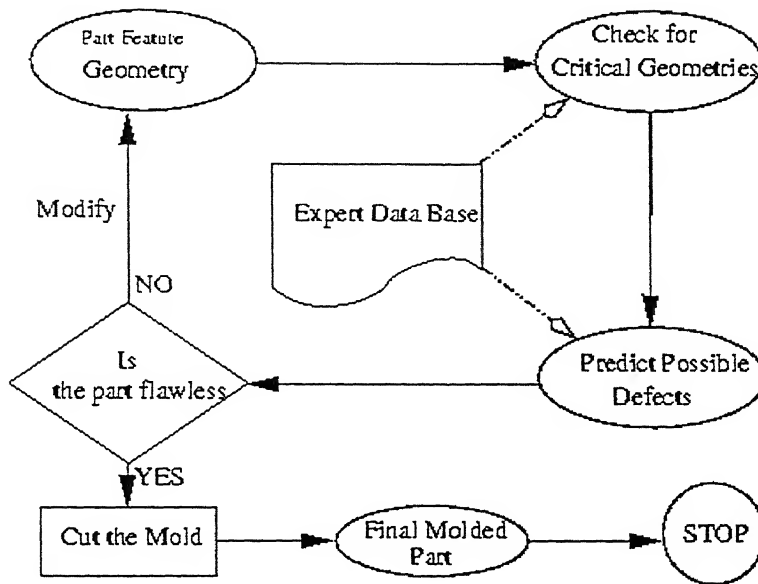
The concurrent engineering approach differs from normal approach as shown in Fig. 1.4. Various life cycle issues are considered at design stage itself. Various checks on part design, mold design and part performance is made, at the design stage to arrive at an optimized mold design. The tool is cut only after detailed design and prediction of part performance according to the specifications. This reduces the product development cycle time and overall cost by eliminating the iterations of tool making.



**Fig. 1.4 – The Concurrent Engineering Approach**

Guidelines for Design for Injection Molding can be summarized as:

- Design for minimum number of parts (integration of parts)
- Design parts for geometries with minimum or no defects
- Design parts for multiuse
- Avoid separate fasteners
- Avoid flexible components (e.g., rubber hoses)



**Fig.1.5 – The Design for Injection Molding Approach**

One such approach of designing parts for minimum or no defect is explained in figure 1.5.

### 1.3 Object Oriented Product Design

Computer aided product design (CAD) has become a potential application area of computers in industries. It acts as foundation platform for any integrated product design system. In order to model and machine a shape using a computer, it becomes necessary to produce a computer compatible description of that shape. It is a kind of mathematical model, which can map the desired surfaces quite accurately. The most promising

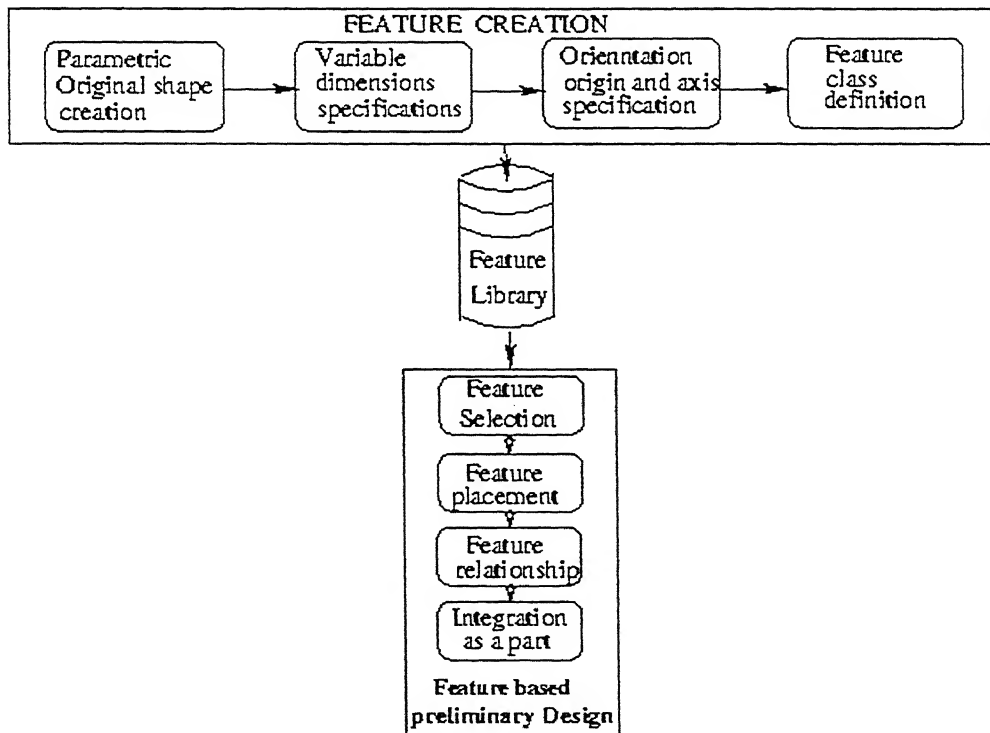
description method was identified as parametric surfaces. The theory of parametric surfaces was well understood in differential geometry but their potential for representation of all kind of surfaces in computer aided design environment were not known at all. The major breakthrough in CAGD came when theory of Bezier surfaces and Coons patches later combined with B-spline methods [Farin, 1990]. This allowed defining any surface might be a complex free form surface, mathematically and finally displaying it on screen for rendering. This on screen display and rendering in 3D space is known as 'Modeling' and has become an important stage of any computer aided object oriented product design system.

## **1.4 Design with Features**

Since most of the geometric modeling system including B-rep and Constructive solid geometry (CSG) does not capture any deep understanding of the system, they are in general unable to support sophisticated reasoning capability [Chen and Wei, 1997]. This is a basic necessity when we need to allow user intervention at design stage. In applications such as design for manufacturing, the interaction of the human designer is necessary for design evaluation and decision making. To develop an intelligent computer aided engineering (CAE) system, it is essential to devise a representation scheme for the design, which allows the computer to capture and manipulate the design information, and, ultimately helps in making decisions. The design by feature or feature based design has come out to be one such design method with DFIM approach..

A feature is defined as named entity with attributes of both form and function [Mantripragada et al., 1996]. Form attributes describe the physical geometry of the product, whilst functional attribute describe the purpose or functional aspects of the product. Since form feature can represent at least some aspects of design intent and product functionality, form feature methodology has been employed in development of mechanical design facilities using this concept of 'design with feature'. It is believed that feature based modeling has several advantages over conventional CSG and B-Rep modeling approaches are further discussed in the next chapter.

Typical injection molded part contains features such as walls, ribs, bosses, holes etc. This enables the designer to use standard library of features to construct the part and incorporate useful design information during the construction stage. Every feature is treated like a record with a set of information fields that carry information about the feature and its relationship with other features. In addition, it may contain some information that is specific to a particular feature, depending upon its type and functional requirement. By following this kind of approach, the system has access to the complete feature information required for the analysis and evaluation of the design. Each feature now can be analyzed independently and in conjunction with other features for ease of manufacture.



**Fig. 1.6 – Architecture of Design with Features**

Feature based design is becoming one of the fundamental design paradigm of CAD systems. In this the basic unit is feature and part is constructed by a sequence of feature attachment operations (figure 1.6). The type and number of possible feature involved

depend upon product type, the application reasoning process and the level of abstraction. Therefore to provide CAD systems with a basic mechanism to define features that fit the product needs seems more appropriate than trying to provide a large repertoire of features covering every possible application [Haffmann and Robert, 1998].

## **1.5 Knowledge Based Engineering (KBE)**

Increasing competitive pressures and higher customer expectations are compelling every manufacturing company to seek out greater efficiencies in each step of their product life cycle: planning, design,, engineering, manufacturing, distribution and support. As new computer systems are being designed to support efficiency improvement in all these life cycle areas, it is inevitable that the largely separate CAD, CAM, and analysis systems of today will evolve in to complete, integrated Product Life Cycle Systems (PLCS). This integration will come about as continuing efforts to achieve concurrent engineering demand, the exchange of data and knowledge among the various life cycle domains.

Knowledge based engineering (KBE) is defined as execution of engineering task using knowledge, that is not normally immediately available to the designer or engineer, and that has been purposefully accumulated and stored for use by the designer or engineer, usually but not always in some computer mediated form [Penoyer et al., 2000].

A KBE system can be any one of followings:

- A computer system used for engineering
- A system focused on a distinct representation of knowledge, and application of that knowledge to specific problem cases
- A system characterized by deep penetration into the problem domain, capable of dealing with the details of individual problem cases, not merely general issues common to all problem cases

- A system that reason through a problem solving process using pattern matching and rules of logic, rather than computing a solution using a mathematical model

The design and molding task of injection molding parts with desired properties is a costly process dominated by empiricism, including the repeated modification of actual tooling. The engineering tasks involved in injection molding are the creation of geometry of parts and molds, and the choice of material and processing parameters. The current practice is highly empirical since it has been difficult to predict the performance of designed part analytically before it is actually made and tested. It requires the adhoc use of expertise accumulated over the years and/or expensive time consuming iterations involving prototype tooling. The empirical approaches have shortcomings that actual results are uncertain and the success of design can be confirmed only through time consuming prototype testings.

A knowledge-based system for prediction of mechanical performance of the injection molded part viz. occurrence of warpage, probable defects and dimensional inaccuracy of the part at the design stage, will obviously be the first stage towards making an injection molding design system [Yong, 2001]. Standard product design guidelines and heuristic knowledge of injection molding can be formalized as design rules for the expert system. It acts as a pre production diagnosis tool for injection molding. The present work is an attempt in this direction.

## **1.6 Integration of KBE and CAD**

The integration of knowledge base in to the CAD environment is very important issue and has not yet tried much. Some CAD system developers provide KBE functionality as an integral part of their CAD environment. The other alternative is to provide an open Application Program Interface (API), there by allowing the user to interface any kind of KBE software that might be required for a particular application. Advanced Modelling Extension (AME) of AutoCAD is one such integration platform and has been tried with softwares such as CLIPS or NEXPERT [Yong, 2001]. Experiences in

developing KBE applications in CAD domains lead to believe that API approach is preferable for the following reasons:

- Present and anticipated KBE applications are very diverse in function, knowledge content and mode of user interaction. It is difficult to imagine that one particular implementation of KBE functionality embedded within a CAD environment would be suitable for all conceivable applications
- There are wide varieties of third party knowledge based software systems already available with new innovations being developed all the time. KBE developers must be able to choose from these tools for new applications.
- Knowledge based engineering is a relatively new technology. Practitioners are still learning how to build and apply KBE systems.

User defined CAD environment for feature based part design with the knowledge base of the injection molding is the scope for the present work. Such small, object oriented design platforms have a very distinct advantage over commercial one. They facilitate a very cost effective computer aided design platform for small industries-who can not afford high priced sophisticated CAD and KBE softwares.

## **1.7 Literature Review**

The literature survey reveals that the potential of design by feature approach has been realized and many attempts have been tried on various platforms. The area of application ranges from garment industry [Charlie et al., 2002] to sheet metal parts [Dong et al., 1994].

There are many papers reporting on languages to represent features. Wood et al. [1996] discussed the function of plastic injection molding features. They modeled a feature function relationship for plastic injection molded parts. They classified eleven features in total with fifty different functions. The bases of design studies are interviews conducted with twenty-seven-members of a team mix of industrial designers, tool designers and plastic designers. Their studies revealed that boss, wall, rib, protrusion and depression

feature cover 70-80 % real world part. Haffman and Robert [1998] suggested a procedure for generating and deploying user defined features (UDF), in a feature based design paradigm. The mechanism addresses customization needs in a simple way. The usefulness of the mechanism relies on three basic capabilities: use of standard tools provided by the CAD system, parameterization of UDF's and graphical interaction.

Although the important role that feature libraries can play in CAD/CAM was realized years ago [Shah and Rogers, 1988], but the problem of defining and using feature libraries explicitly was not much addressed. Duan et al [1993] reported a solid modelling tool for a feature based design and manufacture system, which claims that in their system, designers are free to create any kind of feature. Furthermore, designer can construct their own libraries dedicated to specific applications. But the paper does not give details about how this is achieved.

Corbett et al. [1999] developed a CAD integrated knowledge based system for the design of die cast components. The system uses knowledge base systems and in particular feature representation in the area of design for manufacture of die cast parts to alert the designer to any potential production problems. Similar feature based representation and design for manufacturing concept is explored by Mantripragada et al. [1996] for developing a computer aided engineering system for feature based design of box-type sheet metal parts.

Although feature based design is regarded as a promising approach for design but it lacks a formal methodology for system development and operation. One repercussion of this is that feature-based design at present is implemented in a relatively ad hoc manner. Kim and Peter [1994] aimed to address this deficiency by establishing domain-independent presentation formalism for feature based design. The proposed representation formalism consists of feature algebra, a design algorithm and a system architecture/development methodology. The discussed formalism aims to make it possible to develop a feature based design system for a specific design domain in a structured way.

In feature based design, parts are constructed from a sequence of form feature attachment operations. When a feature is edited, all features attached later must be re-evaluated to satisfy the required constraints and shape references in the initial design. Chen et al. [1998] formulated a name matching technique to support the design evaluation procedure. Dong et al. [1994] suggested feature based modelling of welded plate construction that can support process planning of robotic arc welding and CAD base offline robot programming.

Dynamic editing of features enables designers to freely construct and modify parts. Perng and Cheng [1997] proposed a feature base design system for prismatic parts in which predefined 3D features instead of low level 2D lines and points are used as entities for representation and manipulation. The modeled parts are saved as feature-based files in CSG form, while a B-rep form is also created. The feature-based file allows the part design system to be easily integrated into CAPP/CAM systems without complex feature recognition and extraction processes.

Chen and Liu [1999] in their paper on cost effective design for injection molding, addressed and implemented the concept of concurrent engineering to deal with other product development concerns under an integrated system for cost effectiveness module based on the proposed methodology. The effectiveness and usefulness of this system depends upon the completeness and integrity of the knowledge base.

Feature based design is a key factor for Computer Integrated Manufacturing (CIM) environment, Wong and Wong [1995] built one such feature based solid modeler using Advanced Modeling Extension (AME) on AutoCAD platform, with an expert system written using a KBE tool named CLIPS (C language integrated product system). According to the knowledge provided in the rule based system, the design information will be transformed into the appropriate process plan and manufacturing instructions. In his other paper, Chen and Wei [1997] highlighted the limitations of contemporary computer based design tools, and presented a feature based design for net shape

manufacturing (Die-Casting and Injection molding). It supports the practice of concurrent engineering, by providing functions designed specially for net shape product design and online design guidance. A commercial KBE system shell 'NEXPERT' is integrated with the CAD environment of pro/ENGINEER to implement it.

An AI system based on both case and rule based reasoning has been developed by Shelesh-Nezhad and Siroes [1997] for building an intelligent system of plastic Injection Molding process design. Case-Based reasoning is used to derive the first trial setting of processing parameters, while Rule-Based sub system suggests a set of corrective actions to deal with possible corresponding variations in molding.

Yong [2001] built a knowledge based design system to embody the goal of a rational design by integrating two domains of knowledge of injection molding. Heuristic knowledge of design is formalized as production rules and is combined with analytical knowledge from the process simulation. Further efforts in this field may lead to a good integrated injection molding design system.

The concurrent process design involves the simultaneous consideration of product design, tool design, machine selection, production scheduling, and cost as early as possible in the design stage. Knowledge based system is one of the promising approaches to facilitate concurrent product design. Kwong et al. [1997] used black board based system for concurrent process design of injection molding.

Penoyer et al. [2000] discussed knowledge based life cycle systems viz. integration of KBE and C3P (CAD/CAPP/CAM). They defined and described the knowledge based engineering KBE in depth and suggested that CAD developers should not attempt to provide in-built KBE functionality, rather it should be built with open API architecture to allow easy integration of broad range of KBE softwares.

To ensure that the plastic part being designed is manufacturable by injection molding, the interaction between design and analysis is needed to be very intensive. However such

interaction is not supported by current computer aided systems (CAD-CAE), because design and analysis are realized as separate modules. The different data models and thus poor communication is one of the reasons. Data transfer between different modeling and analysis is still not smooth and standardized. Deng et al. [2002] in their recent paper reported to have developed a CAD-CAE Integrated Injection Molding design system, which uses an integrated data model for both design and analysis. The system is built on top of existing CAD and CAE systems, which not only greatly saves time but also makes full use of the strong functionality of commercial packages. In this application they integrated 'Solid Edge' as modeling and 'Moldflow' as analysis tools. The language and hardware independent software platform with ActiveX automation of the Solid Edge software made it possible.

## **1.8 Scope and Objective of the Present Work**

Injection molding is most wisely used plastic part molding process. The high cost of mold stresses the need to consider guide rules at the design stage itself to optimize the product development cost. The guide rules and heuristic knowledge earned by experience can be better utilized when the design platform is structured in such a way that it provides a layman's modeling environment.

Boundary representation (B-Rep) and constructive solid geometry (CSG) are two most commonly used modelling techniques. Since they focus on building model with low level geometric details, they are quite different from how a human designer designs a product. It also requires complex algorithms for feature extraction and feature mapping as an important link for CAD/CAM integration. This integration is still not reached a level when a smooth transition can be assured without designer intervention. It seems more reasonable to construct a model in terms of meaningful identities such as form features, rather than simple point or line. Since form features can represent at least some of design and product functionality, form feature methodology has been tried in the development of mechanical design using a concept known as 'feature based design' or 'design by feature'.

The very high tooling cost of the injection molding necessitates considering the molding issues at design stage. The concept of concurrent engineering has been proposed to reduce the product development time and involved cost. It suggests considering product, process and all life cycle issues, through all the phases of development cycle.

The objective of the present work is to develop a feature based design platform for injection molding using predefined 3D part features viz. plate, wall, rib, boss and gusset as design primitives with its process knowledge base. As the product geometry plays an important role, the feature related product design guidelines and heuristic knowledge is translated in to design rules, which warns the designer for critical geometries of feature, leading to defected molding.

## **1.9 Organization of the Thesis**

**Chapter 2:** The methodology of feature based modeling and limitations of present CAD/CAM integration are discussed briefly. The importance of form features as preferred entity for new age design modelers is highlighted. The important designs by feature approaches are compared. The most common features for injection molded part, which can be included in the present work, are shortlisted.

**Chapter3:** This chapter focuses on importance of product geometry for an injection molding. The product design guidelines with heuristic database have been collected. It acts as a platform for knowledge base of the developed system to warn the designer for probable defects.

**Chapter4:** The chapter discusses the system design and implementation part. The most common modelling schemes are discussed in short. The data structures used for making the system is included. The software features of the developed system are described. Finally it is tested with a case study.

**Chapter 5:** Conclusion and scope for future work is presented in the last chapter.

# Chapter 2

## Feature Based Modelling

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As discussed in the previous chapter, use of features for part modelling has come out to be a key to integrate design and molding. This feature based design in relevance to injection molding is discussed in this chapter.

### 2.1 Application of form features in CAD/CAM

The impetus of features is to devise a method, which can carry information throughout the product life cycle. Therefore, features should contain geometrical and technological information as well as the molding semantics. To cover the complete product life cycle and to include design, analysis and manufacturing aspects, feature can be categorized in to form feature, precision features, material features and assembly features [Shah, 1991]. In recent years, form features have been used increasingly in CAD/CAM to define product information. The meaning of features is application-independent. Thus, it is not unusual that even for form features; there exist different definitions in association with different kinds of application domain as viewed by different researchers. For instance, some of the definitions are:

“a set of connected faces related to a specific manufacturing process” or

“a geometric form or entity whose presence or dimensions are required to perform at least one CIM function and whose availability as a primitive permits the design process to occur”.

For CAD/ CAM integration, there are mainly two approaches implemented viz. feature recognition from solid models and feature-based design. In feature extraction approach, features are automatically or interactively recognized from the geometric model of the object. On the other hand in feature-based design approach, a product model can be built using pre-defined features from a feature library.

### **2.1.1 Feature Recognition**

Feature recognition includes procedures to recognize features from a CAD database using feature recognition techniques. It uses lower level geometric entities such as faces, edges and points and endeavors to automatically recognize and extract appropriate features from a geometrical model. This information is then organised in a feature-based structure. Geometric reasoning techniques are used to interrogate the data structure of the geometrical modeller. The geometrical modeller in consideration should usually be solid modeler; otherwise the amount of data available in the geometric model may not be sufficient for the geometric reasoning process. Substantial research efforts have been expended and some notable results have been published [Joshi and Chang, 1987] [Woodwark, 1988].

Several different approaches and techniques have been tried in the various feature recognition systems. Sectioning methods, convex hull decompositions, boundary-based methods, cellular decomposition are some of them. Feature recognition based on common approaches is not so easy due to non-uniqueness of representing the part. There are certain other disadvantages with these approaches. The present feature recognition techniques are constrained to part geometry and can't be employed for all types of geometries. Also it necessitates importing data from solid modelling software- the first step in any feature recognition systems- in some neutral file format such as IGES or STEP. Reading such a file format and extracting the information from the file is very tedious work, also the feature recognition algorithms are computationally expensive.

### **2.1.2 Feature Mapping**

Features are viewpoint dependent i.e. each application views the same part in a different way. If a design by feature system is used for defining a part, then the geometric model,

which is domain independent and the feature model, which is domain dependant, are produced simultaneously.

Even for an application that uses a fixed set of features and receives the design model from a closed set feature modeller, it is necessary to enumerate all mapping situations that may arise, and to specify the mapping procedure, in advance. However, this is a difficult proposition and susceptible to combinatorial explosion.

In light of the above problems it is necessary to develop a set of feature building blocks that are domain independent, but are at higher level than just geometry. This formalism is referred as the intermediate geometry representation. The information represented includes interactions between feature and geometric relationship among features. Shah and Rogers [1988] have proposed a set of basic relationships and generic control elements, from which all features are synthesized. It promises that if features are all described in terms of all basic entities (higher level than geometry) it will be easier to transform from one set to another. Thus, the feature based modelling was coined.

### **2.1.3 Feature Based Design**

As stated, modelling approaches of CSG and B-Rep focus on building geometric models with low level geometric details [Zeid, 1998]. It seems more reasonable to construct a model in terms of meaningful higher level entities rather than geometric details. Since form features can represent at least some aspects of design and product functionality, form feature methodology has been employed in the development of mechanical design facilities using the feature based design.

In the feature based design a product is constructed, edited and manipulated in terms of features with certain spatial and functional relationship. The features themselves are functionally defined by attributes, which represent design and manufacturing significance and semantics-geometrically represented, by a set of parameters. It is believed that

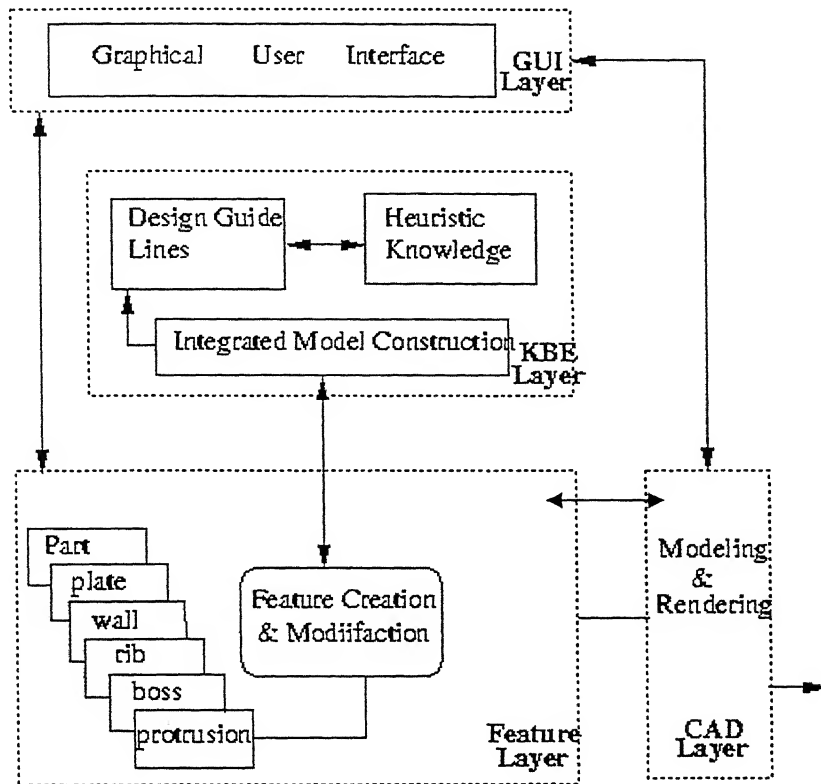
feature based design have several advantages over conventional CSG and B-Rep approaches, such as:

- Providing the ability to capture certain design intents and a better understanding of product geometry and functionality
- A means for designer to abstract the level of design by working with high level shapes instead of geometric details, and
- Encouragement towards standardization leading to an improvement in manufacturability and product quality.

The designs can be carried out with conventional CAD systems, using the feature recognition approach. However feature recognition require that each feature has a predefined pattern primitive or rule based template, and only a limited number of features can be recognized. Further, the actual feature mapping is tedious and complex. Therefore, the approach of feature based design is becoming increasingly more and more popular [Wong and Siu, 1992]. The feature based design or design by features approach provides the designer with a set of feature stored in a feature library. In one of the feature based design approach, a designer, by applying the appropriate modelling operator such as Boolean set operators in the CSG solid modeller, can build the product model with the predefined features. Apart from the shape and geometry, the other downstream function in the product life cycle can also make use of the same feature information.

In a other feature-based model, features can carry information regarding process planing, molding and inspection also. In other words the designer can choose the molding process whilst working on the design. As a product being developed the designer can invoke downstream applications to evaluate the design, for example in terms of moldability, and obtain immediate feedback on the impact of design on these down-stream functions. This also provides the platform to build the model with the principles of 'Concurrent Engineering' or 'Design for Injection molding' [Chen et al., 1998]. Feature modelling should replace the low-level concept by a higher level concept, which has direct significance from the point of view of the designer. Hence, instead of blocks and cylinder as in CSG modeler, the designer describes the part in terms of a blank part and features

such as walls, boss, ribs and holes etc. The structure of the feature based design system implemented in present work for injection molding is shown in Fig. 2.1.



**Fig. 2.1 – Feature Based Design System for Injection Molding**

## 2.2 Design by Feature Approaches

Traditional computer aided design systems can be visualized, as based on design-by-surfaces, the system recognizes shape features by abstraction from surface or solid models. Design by features provides a second design approach. As explained, in this approach, features are incorporated in the part model from the beginning. Generic feature definitions are placed in a library and from which features are instantiated by specifying dimensions and location parameter and various attributes. There are three approaches which are followed for implementation of design by feature methodology.

Destructive Modelling

Synthesis

Dynamic Editing

## **Destructive Modelling**

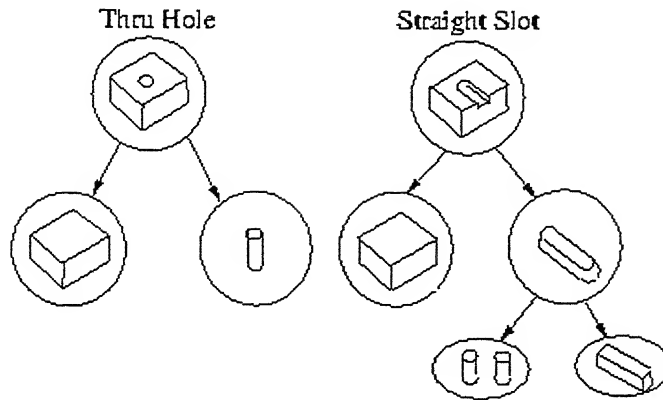
With this approach, the parts are modeled by Boolean subtraction from a base stock model. It involves defining generic features, methods for positioning, generation of solid models and feature validation. The design and manufacturing plans are simultaneously developed by transforming a base stock model in to final part model through the application of operations that correspond to stock removal. The stock can be a cylinder as in case of modeling axisymmetric parts or can be extrusion of any shape (linear sweep) including a rectangular block as in case of prismatic parts. Destructive modelling with features has been implemented in developing process based modelers [Patwa, 2002].

## **Synthesis**

With this approach, the parts are modeled, by adding or subtracting features without a starting base stock. The user is provided with the library of features and Boolean operators, with which one can model the part.

Wong and Wang [1995] used this kind of approach to develop an object oriented design system for computer aided process planning (CAPP). In their implementation the form feature is represented in terms of “cavity volume model” which is the volume to be removed from stock by some conventional machining processes. A form feature, in simple cases can be a solid primitive. In more general cases, a form feature is built up by a set of solid primitives via regularized Boolean operations. Fig. 2.2 shows feature construction. A through hole is represented by a cylinder, straight slot is represented by

the Union of two cylinders and a box, and a pocket is represented by Union of four cylinders and two boxes.



**Fig. 2.2 –Feature Construction by Boolean Operations**

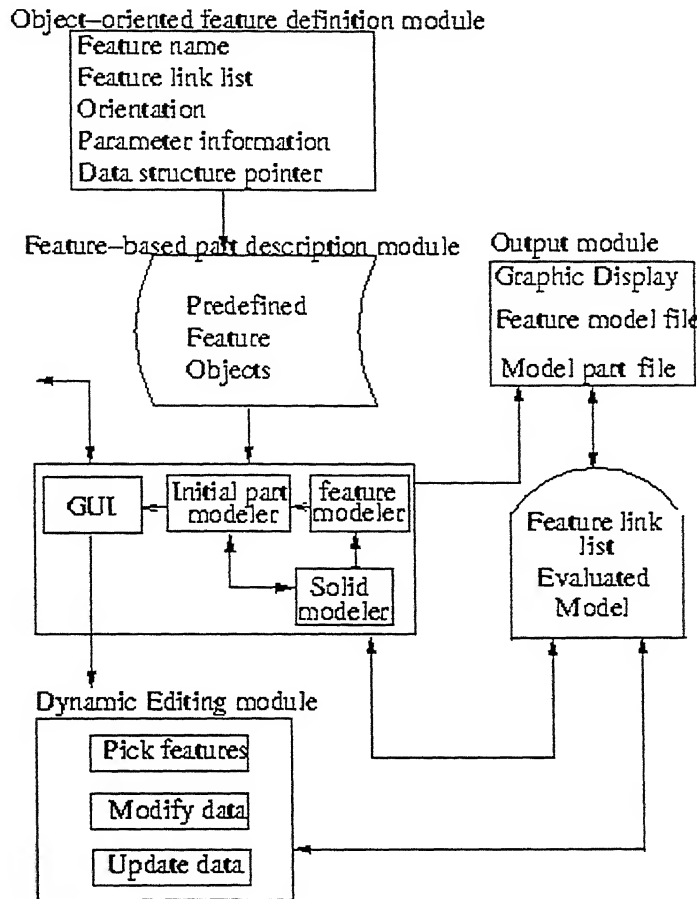
Shah and Rogers [1988] have developed the form feature modelling shell called as FMDS, which provided the facility for creating the product database except the actual definition of features. FMDS can be customized by the organization using it to define the features needed by their designers. Thus feature knowledge is added by the organization to get a complete feature definition system. Once the customization is complete, designers can start using FDMS to define products.

### **Dynamic Editing**

Feature-based design systems mostly focus on assisting designers to construct part feature models. But they do not enable designers to modify models of existing part conveniently. This is one of the limitation of developed featured based modelers, which makes them less user friendly and may be a reason-why they are not appreciated much in comparison to established modeling packages.

A new concept of dynamic editing in feature-based design has been tried [Peng and Chang, 1997]. Dynamic picking and editing is known as ‘dynamic editing’. Instead of low level 2D lines and points, predefined 3D features are used as entities for representation and manipulation. In this, designers can now get real time feature variation

visualization while creating or modifying a part. A selected feature or a modification can be dragged dynamically to a desired position in a user-friendly environment.



**Fig. 2.3 – Structure of Feature Based Design System with Dynamic Editing**

The designed part is saved as feature-based files in CSG (constructive solid geometry) and a B-rep (boundary representation) is also created. Using this feature based file, designers can easily integrate our 3D part design with CAPP\CAM applications, while avoiding the complex processes of feature recognition and extraction. Feature based-design with dynamic editing, with its implementation formalism, is discussed in detail in following sections.

## 2.3 Feature Construction

The development of a feature-based modelling system can be divided into two processes. The first is the definition of feature types or in object oriented terminology, the definition of classes. The second is the definition of a part or product by means of features in an interactive procedure of feature based modelling. In the definition of feature types, a feature is conceived as an 'object' that has a name and number of attribute. The information is stored in a 'class', which acts as a template for objects of specific type. Different classes are organised in a hierarchy, which forms the parent child relationship with the generalized class at the top and specified class at the bottom. The child inherits characteristic from its parent(s). An object is an instance of a class. From the object-oriented point of view, feature types form the template class is defined by the constraints, method and procedures.

A feature is an instance of feature type. Therefore a list of predefined feature can be built easily into feature library. Then, in the definition of a part using the predefined features, features are selected from the feature library. Thereafter, feature parameters such as dimensions and tolerances that describe the shape and size feature features are defined. Finally, the features are then positioned and oriented in three-dimensional space. In their work, Chen and Wei [1997] provided a facility for user defined feature creation and feature library establishment, mechanisms for part geometry creation, manipulation, design information specification etc. Feature library includes predefined features and user-defined features. Most of the Pre-defined features are common for die-castings and injection moldings. They are bosses, ribs, holes, webs, cored holes, drafts, rounds, fillets, grooves etc. The current feature based modelers mostly suffer from the problem of limited number of features available and that to of simple shapes. User-defined features have been tried to make it more versatile [Haffman and Robert, 1998].

## 2.4 Injection Molded Part Features

During the design of plastic components, four types of designers typically interact in the process of development. Contribution of the industrial designers, experts in human factors engineering, ergonomics and aesthetics, all together makes a design perfect. Mechanical design engineers develop the components of a part that make it a complete product. These components fulfill the functions that the customers specify. Tool designers add and modify features necessary for component manufacture. Plastic process engineers also affect the design and the features to ensure that the plastic material will flow and cool as needed by the tool designer.

Wood and David [1996] in their design studies, reported to interview twenty-seven such designers involved in plastic designing work. The interviews covered broad range of topics with an aim to obtain detailed information about the subject's use of features in their design and their basic injection molding process design knowledge. They discussed seventy-nine typical injection molded parts, having 2355 features, categorized in to eleven basic types providing fifty-three different functions. Table 1 displays the common eleven features, which more or less cover almost any plastic part, and Table 2 lists the various functions they serve.

**Table 1 -Features found in study [Wood and David, 1994]**

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Walls
Holes (through and blind)
Ribs/louvers/bars/grates
Protrusions/projections/tabs/flanges
Bosses/pegs
Grooves/depressions/indents/pockets
Slots
Windows/cut-outs
Countersinks
Snap fits
Disks

---

**Table 2-Functions found in study [Wood and David, 1994]**

provide access	convey	link	slide
activate	cover	mount	space
actuate	create	orient	stabilize
aid	display	partition	strengthen
align	eject	pivot	support
allow	enclose	position	transfer
amplify	facilitate	prevent	transmit
assist	fasten	protect	view
attach	guide	receive	
avoid	hide	reduce	
conform to	hold	repel	
connect	join	restrain	
constrain	latch	rotate	
contain	limit	secure	

### **2.4.1 Feature/ Function Data for Plastic Molded Parts**

Following is the basic statistics and result of Wood and David's design studies. The individual features are discussed with their individual role as part feature.

#### **Wall**

No of parts with feature: 96%

No of feature per part: average 5.2

No of different functions served: 34/53

Primary functions: support, cover, strengthen, hold, and position

Average no. of functions the feature provides on a part: 3.1

The wall is the basic structure of all objects, providing the general envelope and supporting or encasting other components. Creating proficient wall designs requires

mechanical and tooling knowledge of the effects of change in wall thickness, plastic injection flow, and corresponding problems associated with the warpage, sinks and other flaws. For example, a wall thickness specified for rigidity may choke the airflow between the louvers, or be too thick to mold effectively. Wall design is influenced by design for injection molding (DFIM) guidelines with respect to thickness and draft. Further more, at times they are tapered or stepped for proper flow control of the injected plastic to certain areas.

### **Holes (through and blind)**

No of parts with feature: 66%

Average no of features per part: 4.6

No of different functions served: 21/53

Primary functions: attach, position, mount, access, limit and reduce

Average no. of functions the feature provides on a part: 1.9

The types of holes found in the study are: through, blind, round, square, irregular, open, slots, cross holes and threaded holes. In general, most holes are specified by the mechanical design engineers, for mechanical fasteners.

### **Ribs (also known as louvers, grills and grates)**

No of parts with feature: 61%

Average no of features per part: 9.0

No of different functions served: 19/53

Primary functions: strengthen, support, guide, hold, and position

Average no. of functions the feature provides on a part: 2.0

Ribs increase the rigidity of a molded part without increasing wall thickness and may facilitate flow during molding. Skillful use of reinforcing ribs can maintain or increase a part's stiffness while reducing the cycle time and amount of material used. Ribs are used in various ways by the industrial designer. Cosmetic louvers are used to create an illusion that vents are present. Occasionally textures ribs are positioned where sinks form that are

different to hide. Ribs according to the mechanical designer interviewed are used for load bearing, spacing, supporting, stiffening, and guiding or for restraining, e.g. preventing paper from entering a location. The rib thickness is sometime varied due to recommendation of the tooling engineering from flow analysis of the part. Ribs are major source of sinks found on adjacent walls; therefore, changing rib thickness is a common strategy for reducing or eliminating sinks. Ribs are also used for control of blush. Blush is the cosmetic flaw (dull spots) caused by improper plastic dispersion during injection. These ribs are put in by the tooling engineer, whose responsibility is to ensure the mold (tools) achieves the desired cosmetic looks.

### **Protrusions (also known as projections, tabs, flangs)**

No of parts with feature: 61%  
Average no of features per part: 6.2  
No of different functions served: 25/53  
Primary functions: hold, position, align, support and attach  
Average no. of functions the feature provides on a part: 2.3

Protrusions are like miniature bosses. Some, called pip marks (tiny bosses/protrusions), are used for dimensioning and tolerancing. Similar pip marks, known as pins, are used for aligning or joining other components on the plastic parts. Small dimples used for aligning labels are also included here. Very small protrusions in injection molding are used for holding the part in to the core rather than the cavity at the separation of the mold. These are usually specified by the tool designer but in some rare cases are specified by the mechanical designer. Some protrusions are used with slots as printed circuit board card guide, while others are used for holding or retaining these boards.

### **Bosses/Pegs (solid/hollow)**

No of parts with feature: 51%  
Average no of features per part: 3.8  
No of different functions served: 19/53  
Primary functions: attach, eject, mount, support and assist

Average no. of functions the feature provides on a part:

2.5

In general, bosses are used by the mechanical design engineers for attaching other components and for injecting the part from the molds. In addition to the main function listed above, bosses are also used to limit the motion of other component, to position or hold either by actual screw-downs or by, merely having a part boss against the boss, to locate or matching adjoining components, dimension and tolerance drivers and ejector pin push-offs. The ejector push-offs usually require bosses to strengthen the ribs or walls that are pushed against in part ejection. Uniform ejection of a feature may be accomplished by using adjacent bosses on each side of the components. With these many uses the bosses therefore a primary feature for dimensioning and associated tolerancing and for stack-up problems.

#### **Grooves (also known as depressions, indents and pockets)**

No of parts with feature: 46%

Average no of features per part: 4.1

No of different functions served: 27/53

Primary functions: confirm to, assist, position and reduce attach/guide/limit/mount

Average no. of functions the feature provides on a part: 1.5

Grooves are commonly used as a cosmetic feature and as such are often dictated by corporate guidelines. In this study the term 'conform to' implies that the feature function is to cosmetically follow the shape of another feature such as wall. This feature is also used for alignment and local positioning. The tooling engineer may use grooves for flow control, restricting flow in various directions and /or evenly spreading the flow in others.

Indents are usually used for 'design-for-assembly (DFA)' as in lead-in guides or aligners. Indents along with tapers and lips are commonly used for self-indexing, i.e., they present a one-way fit, forcing the parts to align themselves.

## **Slots**

No of parts with feature: 46%

Average no. of features per part: 10.3

No of different functions served: 22/53

Primary functions: guide, prevent, hold, transfer and access

Average no. of functions the feature provides on a part: 1.5

Slots are used to guide or transfer air and prevent objects from entering sensitive areas.

Slots may also be used for cosmetics and typically have standard thickness (e.g. 3 mm).

## **Windows/Cut-outs (through and blind)**

No of parts with feature: 44%

Average no of features per part: 2.8

No of different functions served: 14/53

Primary functions: access, align, view, position and guide

Average no. of functions the feature provides on a part: 1.5

Through windows are primarily used to access other parts of the machine. They also provide viewing access to other features or components. It should be noted that the size of window might affect the warpage of the part.

Blind windows are used for label aligning and some also have a 45<sup>0</sup> chamfer for proper label positioning rubber feet. Recessed windows also protect, by preventing the label from inadvertently being peeled off during use.

## **Countersinks, Counter bores**

No of parts with feature: 21%

Average no. of features per part: 2.6

No of different functions served: 11/53

Primary functions: hide, assist, attach conform-to and reduce

Average no. of functions the feature provides on a part: 1.5

Countersinks are subset of holes, but due to their prevalence, they were grouped independently. In most cases, countersinks are used for hiding screw heads and or assisting in leading in screws, snaps or other feature in to a hole. Countersinks were also used to attach shorter screw length or to reduce sinks that form in bosses from excess material.

### **Snap fits**

No of parts with feature: 20%

Average no of features per part: 4.2

No of different functions served: 6/53

Primary functions: hold, secure, attach and fasten, position and mount

Average no. of functions the feature provides on a part: 1.2

Snap fits are typically used to hold or secure two parts together. They are designed for flexibility, therefore, width and length must be carefully controlled during design. Some snap fits are designed to snap in and out easily for DFA and design for disassembly since customer may at times be require to make modifications themselves. Depending upon the part snaps may need to be accessible, coming apart as easily as they go together. In current design, snaps are considered desirable since they replace visible attachment components such as screws.

Snap fits are difficult to design, since usually they require slides to be added to the tool, which increases the cost of the tool, unless snaps are incorporated in to the separation of tool. Snaps made outside the part are preferred, since they can be removed, repaired and replaced easily.

### **Disk and Ring**

No of parts with feature: 11%

Average no of features per part: average 3.1

No of different functions served: 7/53

Primary functions: strengthen, support, align, space and reduce

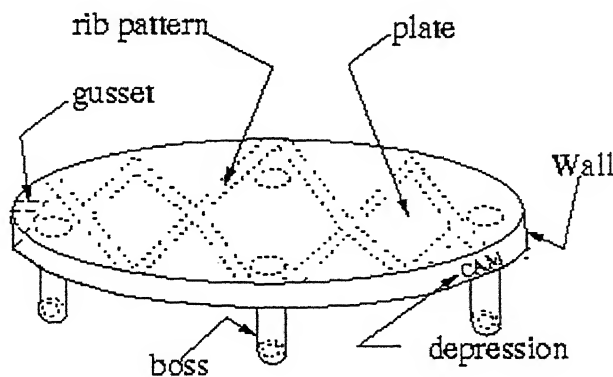
Average no. of functions the feature provides on a part: 1.4

Disk is not a commonly used feature. One used cited in the interview is for the feet of a product. These feet replace the rubber feet that are normally specified when environmental condition would cause the rubber to deteriorate.

A subset of disks is Rings. They are used to reduce (material/sinks) and strengthen with the transmission of energy and material. Rings are used specifically for reducing sinks. When more than two walls come together, the extra material may cause a sink. To reduce this possibility a ring or a boss with the hole in it joins the ribs together.

## 2.4.2 Most Common Features

It is evident from the Table 3 that the top five features i.e. wall, hole, rib, protrusion, and boss represent the majority of features and covers more than  $\frac{3}{4}$  the of the injection molded parts. Thus we have also included these five in the feature library created for the present work. . The table 3 summarizes the information.



**Fig. 2.4 – The Features of a Plastic Stool**

Figure 2.4 illustrates the features of an injection molded plastic stool.

**Table 3 - Summary of Feature Information**

Feature Name	Percentage of Parts with Features	Average No. of Features/part	No. of Different functions	Average No. of functions/ feature /part
Wall	96	5.2	34	3.1
Hole	66	4.6	21	1.9
Rib	61	9.0	19	2.0
Protrusions	61	6.2	25	2.3
Boss	51	3.8	19	2.5
Groove	46	4.1	27	1.5
Slot	46	10.3	22	1.5
Window	44	2.8	14	1.5
Countersinks	21	2.6	11	1.5
Snap	20	4.2	6	1.8
Disks/Rings	12	3.1	7	1.4

The chapter focuses on importance of product geometry of an injection molded part. The product design guidelines with heuristic knowledge database have been presented. It acts as a platform for knowledge base of the developed system.

### 3.1 Basic Process Factors in Injection Molding

The basic process factors in an injection molding process, which affects part quality, can be categorized as:

1. Material Parameters
  - Pressure-Volume-Temperature (PVT) behavior of the polymer
  - Viscosity
2. Geometrical Parameters
  - Wall thickness of the part
  - Constraints from ribs, boss and inserts
  - Effect of other factors such as draft, radii, depressions and projections
  - Number of gates, gate location, type of gate, gate thickness and area
3. Molding Parameters
  - Fill Time
  - Packing Pressure Level
  - Mold Temperature
  - Melt Temperature

The quality of an injection-molded part depends upon the interaction of these three groups of parameters.

The geometrical parameters can be further subdivided in to the following categories:

- Parameter related to product geometry
- Parameter related to mold geometry

Product geometrical features viz. parts wall thickness and variation, ribs, bosses, depressions, projections etc. falls under first category. Mold related parameters viz. Gate location, no of gates, size, manually or automatically trimmed gates, runners, cooling channels etc. fall under second category.

The geometrical parameters of the product have been considered in the present work for developing the product design system for injection molding.

### 3.2 Faults in Injection Molded Components

A careful scrutiny of almost any injection molded plastic product will reveal at least one minor defect. Some defects are so small as to be insignificant. Others may be quite easily seen and identified, even by an untrained person.

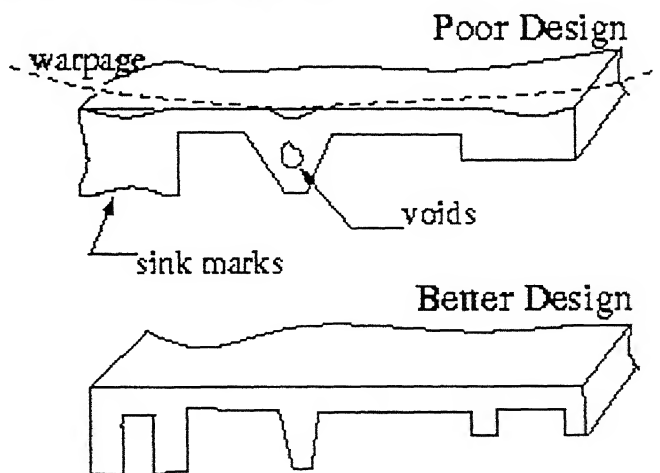


Fig. 3.1 – Poor Geometry Resulting in Defects

Faults in injection moldings may be due to a number of causes arising from different elements of the process. Poor control over the process parameters or machine malfunctioning can be a cause of faulty components. One of such reason happens to be the product geometry. Part defects such as sink marks, voids, warpage, witness marks, poor surface finish etc can be prevented by taking certain precautions while deciding the geometry of a product as shown in figure 3.1.

### **3.3 Rejection Rates**

Dimensional variability and defective moldings in injection molding is a common problem in the plastics industries, leading to very high average rejection rates. Many of the producers face rejection rates of the order of 40-60% [Bown, 1979]. Although the defected moldings can be recycled saving material cost but it directly reduces productivity by increased part rejection and slowing down the automated assembly process.

Thus DFIM principles are applied at design stage of the injection molding, it can reduce the rejection rates drastically and save the productive time of automated molding machine together with recycle overheads.

### **3.4 Product Geometry**

The viscous and fast solidifying flow front of polymer melt puts stringent conditions on the geometries, which can be molded flawless. The part geometry such as cross-section, shape, flow channel required for melt front, interference or junction of two features such as ribs boss etc make the product geometry very influential in getting molded part without any defects.

All these product feature specific issues are discussed in the following sections of this chapter.

## 3.5 Design Guidelines for Injection Molding

In any IM product development cycle, the three areas - product, design, and process - are all interrelated and the appropriate rules in each area must be followed to ensure injection molded part a quality product.

The experiences of designers converted in to heuristic knowledge database have been collected in the form of design guidelines. The basis of almost all the guidelines can be summarized as follows:

- Use uniform wall thickness throughout the part. This will minimize sinking, warping, residual stresses, and improve mold fill and cycle times.
- Use generous radius at all corners. The inside corner radius must be a minimum of one material thickness.
- Use the least thickness compliant with the process, material, or product design requirements. Using the least wall thickness for the process ensures rapid cooling, short cycle times, and minimum shot weight, to reduce unit product cost.
- Design parts to facilitate easy withdrawal from the mold by providing draft (taper) in the direction of mold opening or closing.
- Use ribs or gussets to improve part stiffness in bending. This avoids the use of thick sections, thereby saving material and cycle time.

### 3.5.1 Part Feature Guidelines

The design guidelines can be further classified based on the most common features.

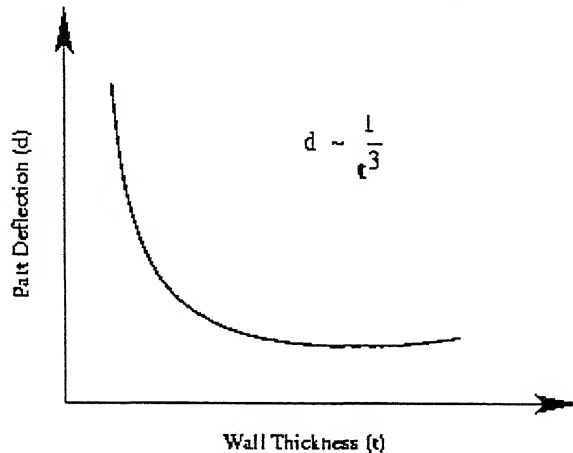
- Wall thickness guidelines
- Hole/ Depression guidelines
- Rib guidelines
- Protrusion guidelines
- Boss guidelines
- Radii, fillet and corners guidelines

The typical plastic part can be considered to have a shell type configuration with a basic surface and features which are attached to it to meet the functional requirements.

Following three factors primarily govern the choice of wall thickness of the part:

- Part design for stiffness
- Cooling time
- Flow length

The deflection of a part under a given load is proportional to function of the wall thickness. It decreases as the wall thickness increases (Figure 3.2). A ribbed part can meet part stiffness specifications with a lower wall thickness.



**Fig. 3.2- Stiffness v/s Wall Thickness**

A major issue in injection molding part design is to determine nominal wall thickness. The wall thickness depends on the structural requirements, process window on PVT behavior of the material in use. Specific structural requirements determine the minimum wall thickness. The material viscosity determines the achievable flow length. Figure 3.3 shows the effect of wall thickness on flow length. The gating scheme and the process window can be adjusted to achieve the desired flow length for a given material.

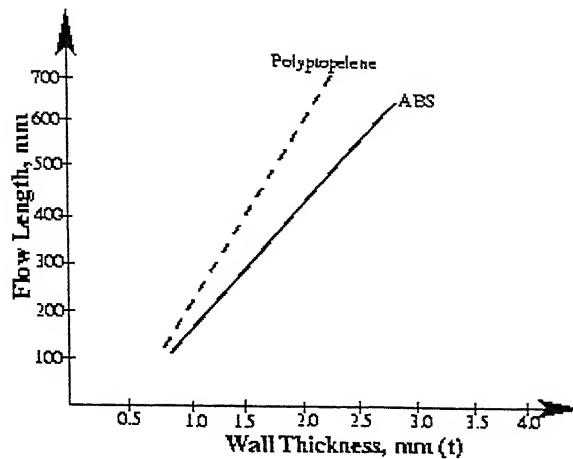


Fig. 3.3- Flow Length Variation with Wall Thickness

As mold cooling accounts for more than two thirds of total cycle time (Fig. 1.2). Uniform cooling improves part quality by reducing residual stresses and maintaining dimensional accuracy and stability. Cooling time is a function of mold wall temperature, melt temperature, material properties and part wall thickness. The equation shown here gives a rough estimate of the cooling time for injection molding.

$$\text{Minimum Cooling Time} = t_c = \frac{h^2}{\alpha \pi^2} \ln \left| \frac{4}{\pi} \left( \frac{T_M - T_W}{T_E - T_W} \right) \right|$$

- Where -
- $\alpha \Rightarrow$  thermal diffusivity of the material
  - $h \Rightarrow$  plate thickness
  - $T_w \Rightarrow$  mold wall temperature
  - $T_m \Rightarrow$  melt temperature
  - $T_e \Rightarrow$  ejection temperature

Figure 3.4 shows the variation of estimated cooling time with the wall thickness of the part. Cooling time increases in a non-linear fashion with increasing part wall thickness. The cooling time for a semi-crystalline material like polybutylene terephthalate is always higher than that for an amorphous material like a blend of polycarbonate and ABS.

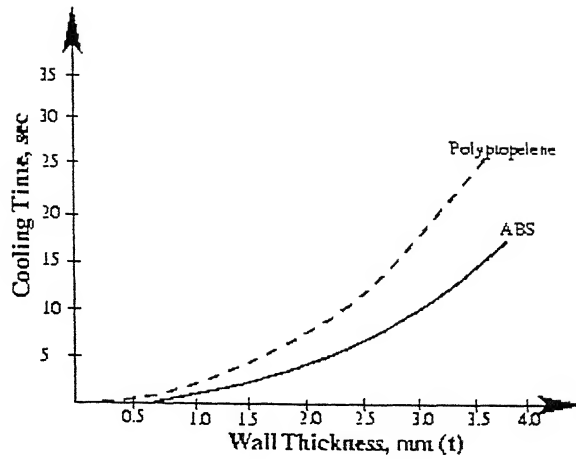


Fig. 3.4- Cooling Time Variation with Wall Thickness

The Figure 3.5 shows a typical temperature history in the cavity during a complete injection molding cycle. The gate freezes off first because it is thinner than the cavity. Once the part temperature is well below the polymer freezing temperature, the part is ejected.

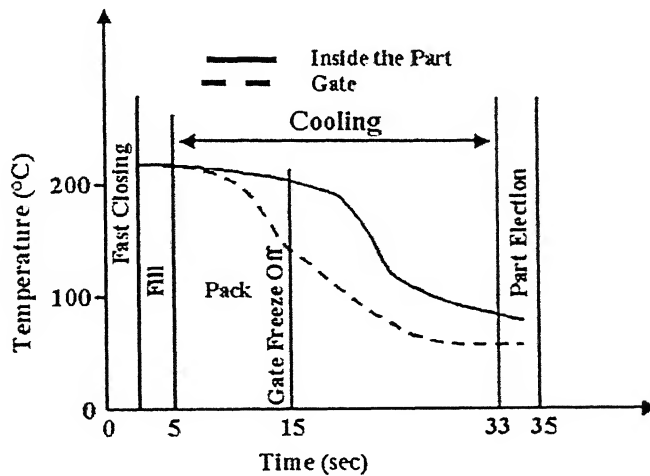


Fig. 3.5 Temperature history of molding Cycle

As it is clear from the temperature history of molding cycle, the cooling time should always be optimized to reduce the typical product cycle time and thus the cost of molding. Also it is noted that wall thickness affects it the most.

### 3.5.2.1 Wall Thickness Design

The wall thickness considerations can be summarised as:

- Application Requirements - Structural requirements including strength, impact, fatigue or deflection will be influenced by the wall thickness selected. Electrical loads may also impact on the wall thickness.
- Moldability - The size of the part and the ability of the material to fill the furthest point can determine the minimum wall. The maximum flow length is also a function of tool design with gate location and number of gates used.
- Agency requirements - For some agency properties, the rating is based on a minimum wall thickness which the part design must meet or exceed to satisfy. This would be the case for UL flammability.

The wall thickness specified typically should meet all the considerations listed above. From a cost standpoint, the thinnest wall utilizes the least material and results in the fastest molding cycles. Following are the guidelines to decide the part's cross section and thickness from molding point of view.

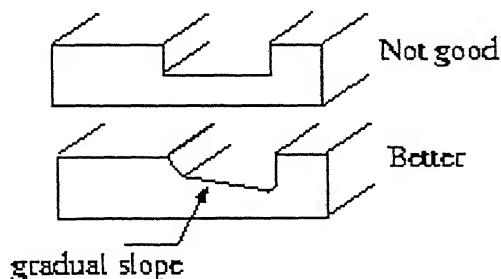


Fig. 3.6 -Wall Thickness Transition

Guideline		Basis
g1	The basic wall of the part should be kept uniform. Avoid overly thick or thin sections	This provides for even flow of the melt during injection. Even cooling and shrinkage that controls part warpage and reduces stress
g2	Coring should be employed where possible to eliminate material masses in the part	Coring results in more efficient designs and faster more productive cycle times. It also provides more uniform shrink and avoids sink marks
g3	When wall thickness transitions cannot be avoided, the transition should be made gradually, on the order of 3 to 1	The gradual transition avoids stress concentrations and abrupt cooling differences
g4	The part and the gating should be designed so the melt flows from the thicker section to the thinner section	This avoids a restricted flow and reduces molded in stress. It also allows for more uniform packing
g5	Avoid sudden changes in wall thickness by using transition zones	It eliminates stress concentrations and reduce sinks, voids, and warping
g6	Part should be designed with minimum wall thickness consistent with functions and mold filling considerations. Minimum -not less than 0.5 – and not more than Max 5 mm.	The thinner the wall the faster the cooling, cycle time is short, resulting in the lowest production cost. The low wt part consumes less melt and thus less product cost
g7	Range of thickness variation Max 0.3 inch per 5 inch of span Min 0.05 inch per 5 inch of span	It avoids short shot
g8	Use gussets if abrupt changes can not be avoided	It prevents warpage

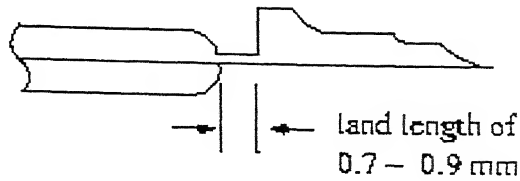


Fig. 3.7- Use of Land

### 3.5.2.2 Holes and Depression Design

Holes are openings for attaching components or fasteners, or for providing vents. Cores are used in the mould to generate hole or depression features. As the Injection molding is a high-pressure process and the viscous melt can deflect or even bend core pins in the mold. It can be avoided by following guidelines.

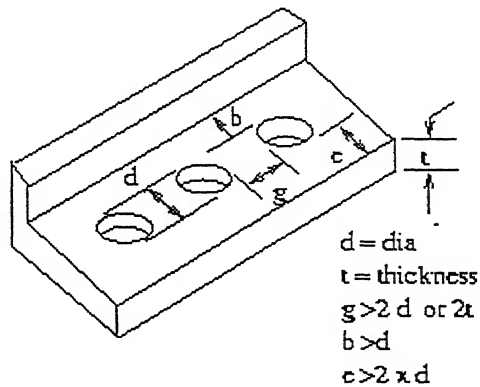


Fig. 3.8- Hole Proportionate Dimensions

Guideline		Basis
g9	For blind holes, the length over diameter ratio should remain below 2. As the diameter of the hole increases above 3/16 inch, the length over diameter ratio can increase to 3	The strength of the core pin to withstand the pressures applied by the advancing melt are best addressed by relating the cross section of the pin to the length of the pin

g10	For through holes, support of the core pin can be obtained on both ends or the pins can meet in the center, which allows the diameter to length ratio to increase to 4. For diameters greater than 3/16 inch, the length to diameter ratio should remain below 6	Because of the increased support, a through hole can be twice as long as a blind hole without deflecting on the injection cycle.  Exception- The length of a core pin may exceed the guideline if a fill pattern is such that a balanced force is developed on the core pin
g11	A vertical step of approximately 0.015 in (0.381 mm) may be considered around the open end of a cored hole	This allows for slight mismatch in the mold and the core pin to be part of a larger diameter doll needed for mold design
g12	A note identifies areas where weld lines are unacceptable because of the high loads and inadequate strength	Warning to a mold designer or processor about structural requirements as they relate to molding.
g13	The mold design should direct the melt flow down the length of slots or depressions and attempt to locate knit lines in thicker sections	A flow as described in the guideline will result in the least molded in stress and knit lines are bolstered by the increased section
g14	The distance between two holes or one hole to the edge of the surface should be at least $2 \times$ the nominal wall thickness or $2 \times$ the hole diameter if that dimension is larger	Adequate material around a hole is needed for strength particularly when knit lines are likely to be present
g15	The edges and corners of a depression should have a minimum radius of 0.015 in (0.381 mm) The preferred radii is 50% of the nominal wall thickness	The incorporation of radii aids in the molding and strength of the part

g16	Avoid adjacent holes have min gap of 2 x thickness/ diameter of the hole	To assure sufficient melt for each hole when solidifies.
g17	Min gap of hole from the edge > 3 x diameter of hole	It avoids sinks
g18	Avoid holes in a line	For every cored hole there is a weld line so avoid placing them in line

### 3.5.2.3 Rib Design

Ribs are used to support wall or plate feature of the part. It is basically for providing strength to the part. Various rib pattern and cross section can be designed. For example 'Z' rib pattern is provided to impart torsional strength. Ribs should follow proportional thickness guidelines shown in Fig. 3.10.

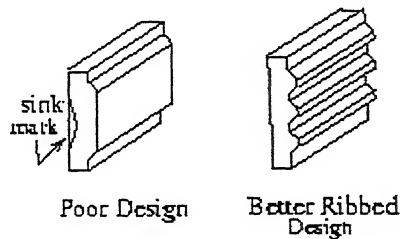
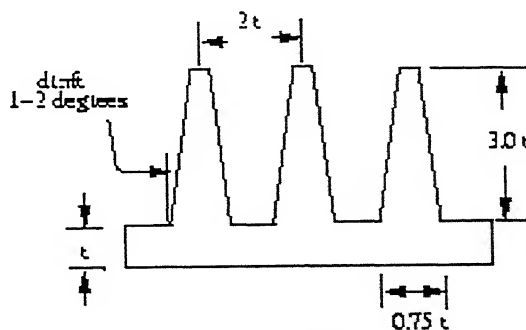


Fig. 3.9- Use of Ribs

Guideline		Basis
g19	The thickness of the rib at the intersection with the nominal wall should be 50 to 60% of the nominal wall	The intersection can develop amass of material if rib thickness gets too great. This can affect the fill pattern within the mold and can result in sink on the wall opposite the rib

g20	Maximum rib height: $h=3 \times$ nominal wall thickness	Deep ribs become difficult to fill, may stick in the mold on ejection, and with draft they can generate a material mass at their base
g21	Typical draft for ribs is 1 to 1.5°. Minimum draft should be 1/2° per side	Draft is necessary to aid ejection of the part
g22	The intersection at the base of the rib should radii. 25 to 50% of the wall thickness. A minimum radius of 0.015 in (0.381 mm) is suggested	The radius eliminates a sharp corner and stress concentration. Flow and cooling are also improved
g23	Spacing between two parallel ribs should be a minimum of $2 \times$ wall thickness	This keeps the mold from developing a hot blade and cooling problems
g24	Position ribs in the line of flow to improve filling and prevent air entrapment. The preferred flow of the melt in the mold is down the length of the ribs.	The flow across the ribs results in a branched flow and can trap gas or hesitate because of the thinner section. Hesitation can result in stress and hinder fill



**Fig. 3.10- Ribs Proportionate Dimensions**

### 3.5.2.4 Boss Design

Any feature that stands up off the nominal wall is a kind of projection. Boss is also a projection with hollow circular cross section. It is used as a support, clamping hub or fastening means to reinforce the product.

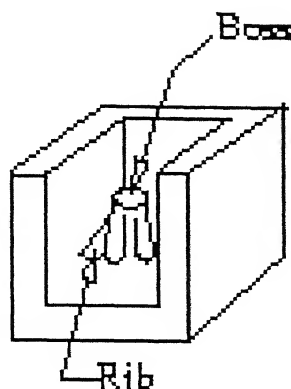


Fig. 3.11- Boss Supported by Ribs

Guideline		Basis
g25	Typically the boss OD = 2 ID	This is the general rule of thumb which allows the wall to increase as the size of the boss increases
g26	The wall thickness at the base of the boss should remain less than 60% of the nominal wall thickness	Wall thickness greater than this guideline will result in a material mass which can produce sink and possible voids. This may also extend the cycle time
g27	The boss height should be less than $3 \times \text{OD}$	A tall boss with the included draft will generate a material mass at the base. In addition, the core pin will be difficult to cool and can extend the cycle time and affect the cored hole dimensionally

g28	The boss should be radiused at the base. Radii at the base should be 25 to 50% of the nominal wall thickness. A minimum radii of 0.015 in(0.381 mm) is suggested	Bosses are often an attachment point and carry significant loads. The intersection of the base of the boss with the nominal wall is typically stressed and this is magnified by a stress concentration if no radii are used. In addition, radii help in molding
g29	The end of a cored hole in the boss should have a minimum radius of 0.010 in(0.254 mm)	A radius on the core pin avoids a sharp corner which aides molding (fill and cooling), and diminishes stress concentration
g30	Draft on the OD is 1/2 minimum	Draft is needed for release from the mold on ejection
g31	Draft on the ID is 1/4 minimum	Designs may require minimum taper to get proper engagement with a fastener. With proper ejection and polishing on the mold, the small draft angle can be accommodated
g32	Bosses adjacent to an external wall should be placed inboard a minimum of 0.125in (3.175 mm) to the edge of the boss OD	This location allows the designer to tie the boss to the wall with ribs and avoids creating a material mass which would sink and lengthen cycle times
g33	Keep the minimum distance of twice the nominal wall thickness between 2 bosses	When features are located too close to each other, thin hard to cool areas in the mold fill develop and can affect part quality and productivity

### 3.5.2.5 Boss as Fastener Design

Guideline		Basis
g34	The ID should be .8 x nominal screw diameter	This is proper dimension for a screw to tap threads in a boss
g35	Screw engagement should be a minimum of 2-1/2 times the screw diameter	Shorter engagement lengths risk stripping the threads during assembly and pull out strength may be reduced
g36	The depth of cored hole should be $-0.032$ in (0.813 mm) greater than the screw length when fully engaged	This avoids bottoming the screw causing undo stress and allows room for displaced material from the self tapping screws, primarily thread cutting screws
g37	A chamfer at the top of the boss is a good lead in for the fastener	The designer can speed the assembly by adding lead in to his design

### 3.5.2.6 Radii, fillet and corner Design

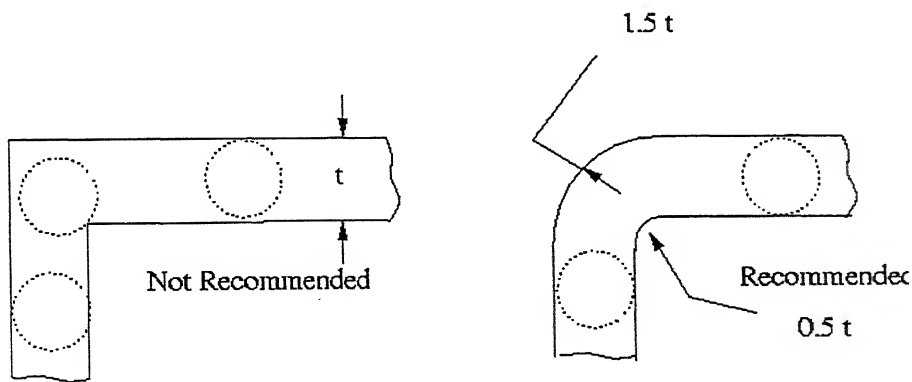


Fig. 3.12- Use of Generous Radius

Sharp corners greatly increase the stress concentration. This high amount of stress concentration can often lead to failure of plastic parts. Sharp corners can come about in non-obvious places. Examples of this are a boss attached to a surface, or a strengthening rib. These corners need to be radiused just like all other corners. The stress concentration

factor varies with radius, for a given thickness. As can be seen in Fig. 3.6, the stress concentration factor is quite high for R/T values less than 0.5. For values of R/T over 0.5 the stress concentration factor gets lower. The stress concentration factor is a multiplier factor it increases the stress.

Actual Stress = Stress Concentration Factor K x Stress Calculated

This is why it is recommended that inside radiuses be a minimum of 1 x thickness

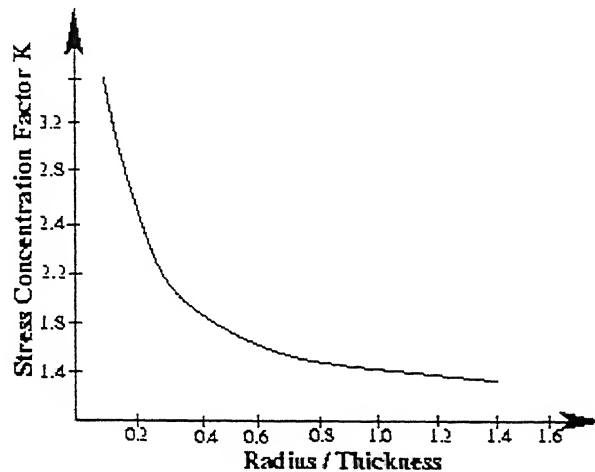
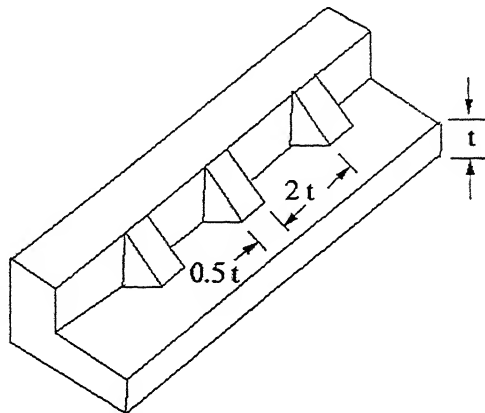


Fig. 3.13- Effect of Radius on Stress Concentration

Guidelines		Basis
g38	Avoid sharp corners or junctions wherever two features or wall meets. Provide radii or fillets. If not possible break sharp corners at least a .005 in or 0.127 mm radius	This is the general rule of thumb which allows the parabolic flow front of melt to pack the cavity efficiently. Sharp corners greatly lead to the stress concentration and can often lead to failure.
g39	It is recommended that inside radius of the corner should be minimum equal to the part thickness	The stress concentration factor is proportional to the ratio of radius to the thickness. $K = r/t$

g40	Typically at corners, the inside radius is $0.5 \times$ material thickness and the outside radius is $1.5 \times$ material thickness. A bigger radius should be used if part design will allow it.	Fillet radiuses provide streamlined flow paths for the molten plastic resulting in easier fills
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### 3.5.2.7 Gusset Design



**Fig. 3.14- Use of Gussets to Avoid Warpage**

Gussets may be considered a subset of ribs and the guidelines for ribs apply to gussets. Both are used to improve part stiffness in bending. Use of gussets also prevents warpage and can reduce the part material thickness thus saving material and cycle time.

Guidelines		Basis
g41	The thickness of a gusset at the intersection with the nominal wall should be 50% of the nominal wall	This will keep the gusset from reading through the nominal wall as sink

g42	The height of the gusset can be 95% of the height of the boss it attaches to. Generally the height will be less than 4 times the nominal wall thick-ness and the preferred height is 2 times the nominal wall	This has to do with the effectiveness of the gussets and the ease of molding with respect to fill and ejection
g43	The length of the gusset may vary from 30 to 100% of the height of the gusset	This addresses the effective-ness of the gusset
g44	The intersection of the gusset with the feature or the nominal wall should have a fillet with a radius of 25% of the nominal wall	The radii get rid of sharp corners which can introduce stress concentrations and adversely affect the molding process
g45	The spacing between gussets should be at least twice the nominal wall thickness	This is the same guideline for ribs and it pertains to the strength and cooling of the mold

### 3.5.2.8 Parting Line and Ejection Design

The designer needs to consider how the molds will apart once the melt solidify. It involves imparting appropriate draft and shutoff. Often design changes to a feature can eliminate the need for action in the mold, saving tooling cost and maintenance costs later on. Guidelines relating to draft, shutoff and parting lines are written below.

Guideline		Basis
g46	On surfaces in the draw of the die, a minimum of 1/2 should be specified. Typical draft is 1. More draft aids ejection but may generate a material mass on sections contained in one side of the mold	Draft is required for release
g47	Keep features in the parting plane to simplify the part. When a stepped parting line is required, allow 7 for shut off. Minimum shut off angle is 5	Drag at the shut off will wear over time and develop flash. Maintenance to restore mold to flash free parts will be more frequent
g48	Specify mismatch on the parting line	Note establishes what is acceptable to the engineer for the molder
g49	Redesign holes in the side walls so that the feature can be obtained with shut off, thus reducing the need forced action in the mold	Taking advantage of design flexibility can simplify the mold, reducing initial costs and minimizing maintenance throughout production
g50	For deep ribs and protrusions, allow for knockouts on the tops of the ribs or at intersections	Knockouts for ejection need to be incorporated into design as they are frequently greater than the section and must be free to travel during the ejection stroke

### 3.5.2.9 Better appearance Design

Ideally the part should be designed with plane wall of uniform thickness without any other geometrical features. But we need such features viz. projections, depressions for various reasons. This results in inferior surfaces due to differential shrinkage. Following precautions will help in getting better part surface quality.

Guideline		Basis
g51	To maintain a Class A surface on a molding, the side behind the appearance surface must be free of projections and depressions. If a projection can not be avoided, then the maximum thickness at the intersection is half the nominal wall thickness	Very subtle changes in the wall section may read through on a high gloss, high quality surface. Even tooling lines made from sloppy fitting lifters may read through noticeably on the appearance surface
g52	Some relief may be available to locate a structural rib opposite a Class A surface if a styling line runs directly opposite the rib	The read through is masked by the styling line
g53	Consider the use of texture on the appearance surface to mask read through of any detail on the opposite side	The texture breaks up a glossy surface and minor read through is not noticeable
g54	Allow 1" additional draft for each 0.001 in (0.025 mm) depth in texture	Increase in draft angle is needed to avoid scuffing and obtain proper release
g55	Textured surfaces stop a preferred 0.060 in (1.524 mm) or a minimum of 0.040 in (1.016 mm) from any parting line.	Terminating the texture improves the durability of the parting line
g56	Raised or recessed letters on appearance surfaces have a minimum radius of 0.010 in (0.254 mm)	The breaking of the sharp edge helps the appearance of the lettering

g57	Print notes for appearance parts. Locate knockouts, gate sand insert lines away from identified appearance surfaces. Specifications include color number, gloss number or texture specification. All appearance and post finish surfaces are identified	To communicate clearly on the part drawing information with regard to appearance
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### 3.6 Implemented Expert Database

As discussed in section 2.4.2 of previous chapter, the five most common features for a typical part are Wall, Rib, Boss, Hole and Projection. Guidelines related to these features have been used as expert database.

# Chapter 4

## System Design & Implementation

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The present work of 'feature based modelling for injection molded parts' can be divided in to following stages:

- Modelling environment
- Library of features
- Expert data base
- Integration of all the modules to make the complete design system

Expert Data base has already been discussed in chapter 3. This chapter discusses the other three modules and their mutual interface.

### 4.1 Geometric Modeling

Geometric modelling is understood as description, processing and storing of the geometrical properties of spatial objects using analytical or approximating methods. Depending on the object class and the tasks to be solved, various modelling techniques have been introduced. These modelling techniques can be classified according to several criteria as will be described in the following paragraphs.

- Analytical vs. approximating techniques
- Vector vs. raster data
- Geometrical dimensionality
- Topological dimensionality

### **4.1.1 Analytical vs. Approximating Techniques**

Analytical modelling techniques are based on closed analytical surface functions or volumetric primitives whereas approximating modelling techniques are based on interpolation methods or on methods of approximation by finite elements.

### **4.1.2 Vector vs. Raster Data**

This scheme of geometrical modelling techniques is based on the internal representation of the data. Topographic objects can be represented by:

#### **Vector data**

The representation of the objects is based on distinct points described by their coordinates in the reference system and their topological relations, especially edges (connections of two points) and surfaces (e.g. represented by closed loops of edges, see below). Vector representations are very compact and thus do not require much disk space. In addition, operations such as geometrical transformations or visualization can be performed rather fast. However, in some situations, e.g. in the context of the union of thematic layers, more complex algorithms have to be applied than with raster data defined on a common grid.

#### **Raster data**

The representation of the objects is based on the elements of a (2D or 3D) matrix. The geometry of such an element (a grid point or pixel) is given by the row and column indices of that element, the offset of the first (e.g. the upper left) pixel of the matrix, and the grid interval. There are two views on the meaning of a pixel in a raster model. First, the pixel can be seen to represent a singular grid point. In this case, the rectangular area enclosed by four neighboring grid points is called a facet of the raster model. From another point of view, the pixel can be seen to represent a rectangular area itself in an integral manner. The value assigned to a pixel describes one thematic attribute of that pixel. Topological information is only contained implicitly: neighborhood relations can

be described by index differences. Topographic objects can only be represented by a set of neighboring pixels having identical attributes. Thus, the manipulation of individual objects is very difficult. However, the structure of raster data is simple, and operations requiring information on surface coverage can be performed rather easily. This is also true for data acquisition, which can, for instance, be performed by classification of satellite images. These benefits are contrasted by the enormous requirements for data storage, (especially for continuous tone data and in particular for 3D raster data), and the high computational costs for tasks such as geometrical transformations.

#### 4.1.3 Geometrical dimensionality

Restricting ourselves to representation schemes containing the third dimension (the height component), there are several possibilities how this can be done

- 2D+1D: The planimetric co-ordinates describe the objects. A digital terrain model (DTM) provides height information in an additional thematic layer so that for each 2D-object point, its height can be interpolated from the DTM.
- 2.5D: The objects are still described by their planimetric co-ordinates. However, for each 2D point, the height is additionally stored as an attribute. As only one height can be assigned to one planimetric position, caves, bridges, etc., cannot be modeled in that way.
- 3D: All information is contained in three dimensions, and all co-ordinates are treated equally. 3D modelling (solid modelling) techniques are essential for modelling man-made objects such as buildings etc. However, the computational costs of common algorithms such as intersections are rather high.
- 4D: Time is contained as a fourth dimension.

Note that using 2D+1D or 2.5D techniques, closed solid objects can not be described. These techniques just provide a surface description of the object, which however is sufficient in many cases.

#### 4.1.4 Topological Dimensionality

Objects in vector data formats are represented by points and their topological relations. Topological relations are described in terms of topological simplices, which are assigned a dimension:

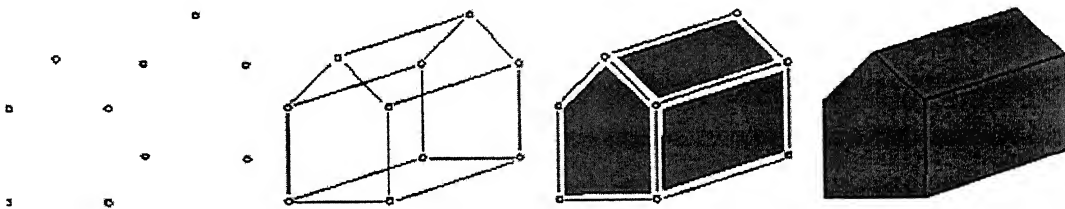
- Simplices of dimension 0 are called nodes or vertices; they correspond to the points of the object.

Simplices of dimension 1 are called edges: each edge connects two vertices.

Simplices of dimension 2 are called faces. In their simplest form, the faces are triangles.

Simplices of dimension 3: volumetric primitives, tetrahedrons in their simplest form.

Depending on the topological dimension used for modelling, four types of 3D object representations can be distinguished (Figure 4.1)



**Fig.-4.1: Object representation methods: point cloud, wire frame model, surface model, and volumetric model.**

In point cloud, the object is just described by the vertices. In case of wire frame model, vertices and edges describe the object. And for surface model, vertices, edges and faces describe the object. In a more general sense than the one described above, the faces can, for instance, be represented by closed planar polygons. For volumetric models, vertices, edges, faces and volumes, describe the object for example as a set of volumetric primitives.

Depending on the object class, different modelling techniques will be appropriate, each technique having its specific advantages and disadvantages. Several criteria described by the following questions can be used to analyze the properties of a certain modelling technique:

- Domain: Which objects can be described by a representation method?
- The set of possible object descriptions: Which semantically and syntactically correct representations can be built using that method?
- Completeness: Which representations describe at least one object or, in other words, are there correct representations which do not correspond to a real object?
- Consistency: Does a representation correspond to exactly one object or not?
- Uniqueness: Does each object have exactly one representation or not?
- Efficiency: How complex are algorithms based on that representation technique?  
What are the computational efforts both in time and memory space?

## 4.2 Modeling of solid objects

Solid modelling is the branch of geometric modelling concerned with the representation of 3D solids. Solid modelling divide 3D space into a part that is “inside” the object and a part that is “outside”. Some paradigms regarding the topological dimensionality of 3D vector based descriptions have already been described in previous section. Of the four classes of representations, only surface and volumetric models can be used for solid modelling techniques. Wire frame models (Fig./ 4.1) do not contain the faces of the object and thus are not unique. However, they are often used for visualization because they can be interpreted easily. There are six common representations in solid modelling:

- Spatial enumeration
- Cell decomposition
- Boundary model *or* Boundary representation (B-rep)
- Sweep methods
- Primitive instancing

- Constructive solid geometry (CSG)

## Spatial enumeration

This is the simplest form of a 3D volumetric raster model. A section of 3D space is described by a 3D matrix of evenly spaced cubic volume elements (*voxels*). All voxels being “inside” the solid object are flagged. Voxel models contain highly redundant information, and thus require much disk/memory space. In addition, topological information is not contained in such models, and operations such as geometric transformations are rather costly. The spatial resolution is restricted by the grid size, i.e. the voxel dimensions. However, Boolean operators such as the union of two objects, can be performed quite easily.

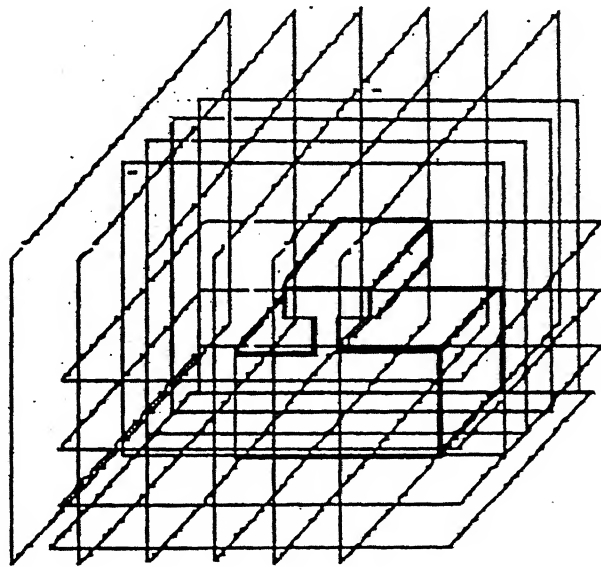


Fig. 4.2 -Cell Decomposition

## Cell decomposition

Cell –decomposition techniques typically use a spatially enumerated model of the part, or part decomposed in to a number of cells. The cells that are to be removed by machining are recognized. A spatially ordered cell decomposition of the part was

produced by a lattice of planes parallel to the major axis as shown in figure 4.2. A hierarchical adaptation of spatial enumeration 3D space is sub-divided into cells which, however, are of different size. A regular variant of this representation based on recursive decomposition of 3D space by cubes is the region octree (figure 4.3). More general decomposition methods make use of cells of different shapes, positions, and sizes. These simple cells are glued together to describe the solid object.

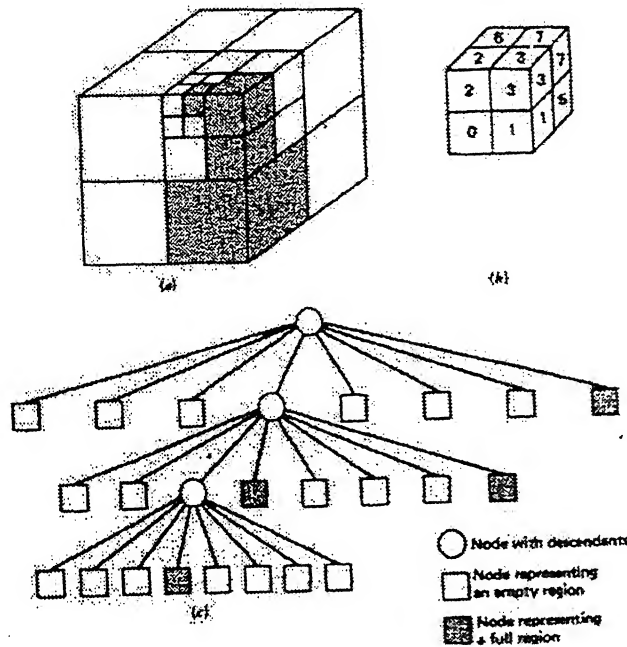


Fig. 4.3 -Octree Encoding

### Boundary Model or Boundary Representation (B-rep)

The object is represented by its boundary, which consists of a set of faces, a set of edges and a set of vertices as well as their mutual topological relations. The boundaries are represented by boundary curves, which defines the surface and which in turn is represented by its end points which defines the curve.

### Sweep Methods

A planar shape is moved along a curve. According to the type of movement, transnational and rotational sweep techniques are possible. These methods are well suited for representing prismatic and rotationally symmetric solid objects.

The locus of points generated by this process defines a one, two or three-dimensional objects. For solid modeling, two ingredients are required, the directrix and generatrix. The directrix is trajectory, which is an analytically definable path and generatrix is an object that may be curve, surface or solid and is moved along the trajectory. Two types of trajectories are depicted – transnational and rotational.

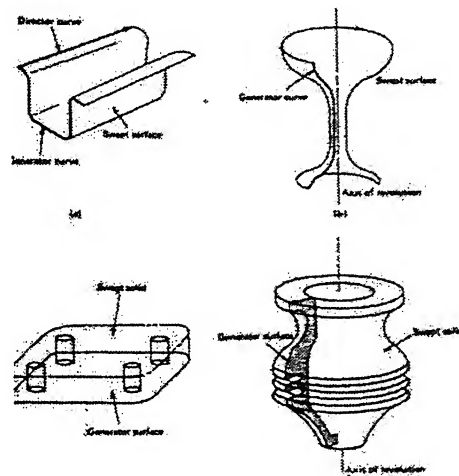


Fig. 4.4 Models generated by sweep

## Primitive Instancing

These modelling schemes provide a set of all possible object shapes, which are described by a set of parameters. Instances of any object shape can be created by varying these parameters.

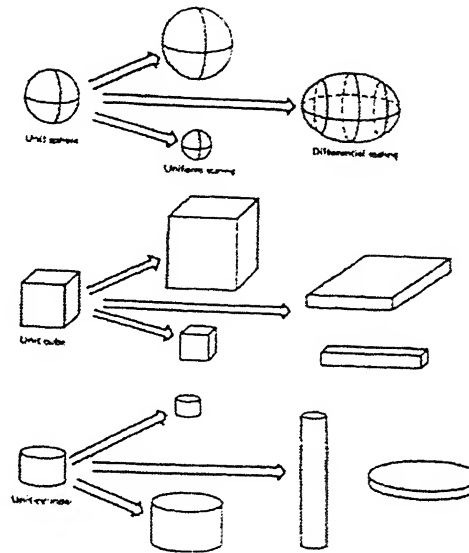


Fig. 4.5- Primitive Instancing

## Constructive Solid Geometry (CSG)

In CSG, primitive instances are combined to form more complex objects by using geometric transformations and Boolean set operations. It is the concept of CSG to provide solid 3D primitives which are described a set of parameters reflecting the object dimensions (Fig. 4.5). The CSG primitives are simple objects such as cubes, boxes, tetrahedrons or quadratic pyramids. They are considered to be bounded point sets in 3D space, and they can easily be combined using Boolean set operations (union, intersection, and difference). The most natural way to represent a CSG model is the CSG tree, which can be defined as follows:

$$\begin{aligned} \langle \text{CSG tree} \rangle &::= \langle \text{primitive} \rangle | \\ &\quad \langle \text{CSG tree} \rangle \langle \text{set operation} \rangle \langle \text{CSG tree} \rangle | \\ &\quad \langle \text{CSG tree} \rangle \langle \text{rigid motion} \rangle \end{aligned}$$

Where primitive is an instance of one of the primitives of the primitive database. The leaves of the CSG tree are the primitives, and the nodes are marked either as a Boolean set operation or with a rigid motion. Thus, in the CSG tree, the history of generation of the solid is stored. The solid itself corresponds to the upper node of the CSG tree (figure 4.5).

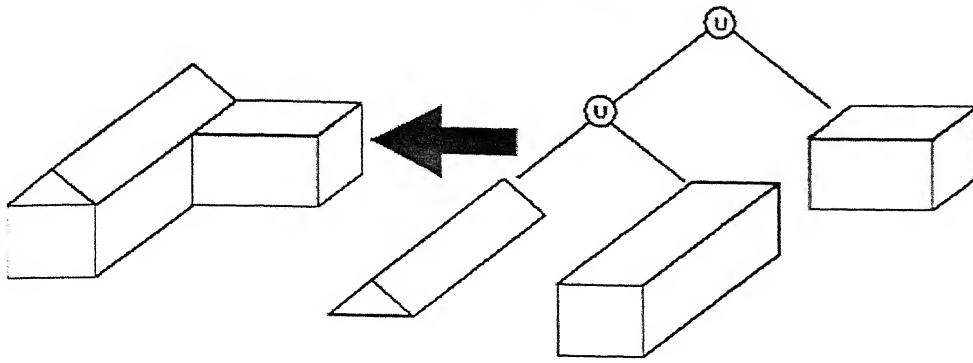


Fig. 4.6 -The CSG model

CSG is a very powerful concept for object modelling in automation procedures for building extraction and for 3D city models, especially well suited for objects which are relatively simple and show symmetries, because many objects can be represented by a combination of simple basic building primitives. CSG trees are always guaranteed to represent valid objects, they are unambiguous but not unique: each CSG tree models exactly one object, but the CSG tree of a given object is not unique because an object can be built in several ways. As Boolean set operations are an integral part of a CSG tree, these operations are closed for CSG trees, e.g., and the union of two CSG trees will again be a valid CSG tree. CSG is not as flexible as boundary representation: the applicability of CSG depends on the primitive set, which can be used. If an inappropriate set of primitives is offered, object modelling using these primitives will become difficult.

Some tasks such as the classification of a point as being inside or outside the solid are very simple to solve using CSG. However, for certain applications, especially for visualization, a boundary representation is to be derived from a CSG model. This operation called *boundary evaluation* is rather complicated. First, the CSG primitives have to be converted to boundary models, and then these models have to be combined using the Boolean set operations, which, as already stated in section, turns out to be very complicated. Note that the conversion cannot be inverted: whereas in CSG trees, the history of generation of a solid model is stored, this information is lost during the conversion to B-rep, and there is no general method available to reconstruct CSG trees from B-rep.

## 4.3 Implemented Modelling Scheme

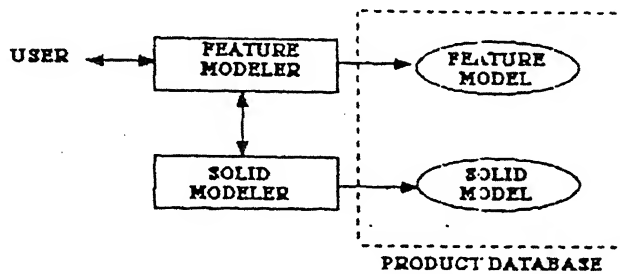


Fig. 4.7 Modeler Structure

Cell Decomposition technique is used for model various features. Only CSG based scheme can not be used since it required calculating the intersection of surfaces and curves and vertices to represent the solid. B-Rep is more complicated to use in the present work. Spatial occupancy enumeration takes more data storage and resolution depends on the size of the cells, hence cell decomposition is the obvious choice.

The basic primitives for the developed system are the parameterized predefined features which are instanced from the feature library and the object is modeled using dynamic editing.

## 4.4 System Design Architecture

### 4.4.1. Data Structures

All the features are predefined and stored in the feature library. The features selected for the system are wall, rib, boss, hole and protrusions. Simple variations of these features are modeled. The features are constructed using standard primitives of OpenGL viz. quads, cylinders, cones etc.

As all the features are composed of surfaces-surfaces are composed of edges-and joining points/vertices generates edges. The data structures are created and maintained as explained here. All the data structures are sequential linked list, which stores the

information in a sequential order, as provided by user interface. Each node of the linked list represents one entity and stores corresponding parameters.

## **Vertex Data Structure**

The parametric feature dimensions given by user is translated and stored in terms of basic entity 'the vertices' or points. Each vertex has a pointer to following vertex. The pseudo code of the vertex data structure is as follows:

```
struct vert_pts
{
    float points[4][3];
    struct vert_pts *next;
};
typedef struct vert_pts vert_pts;
```

## **Edge Data Structure**

This accommodates the sequential list of vertices generating the edges of the features. And of course a pointer to next id.

```
struct edge_vert
{
    struct vert_pts [10];
    struct edge_vert *next;
};
typedef struct edge_vert edge_vert;
```

## **Face Data Structure**

This accommodates the sequential list of edges generating the faces of the features. And of course a pointer to next id.

```
struct face_ edge
{
    struct edge_vert [10];
    struct face_ edge *next;
};
typedef struct face_ edge face_ edge;
```

## Feature Data Structure

A feature is constructed by a set of surfaces. This accommodates the sequential list of faces generating the features. And of course a pointer to next id.

```
struct feat_ face
{
    struct face_ edge [10];
    struct feat_ face *next;
};
typedef struct feat_ face feat_ face;
```

## 4.5 Software Features

The main code is written in C compiler and OpenGL libraries have been used for graphical display of the rendered output. The graphical display of the developed system is shown in figure 4.8 with various 'Radio buttons' and 'Rollout menus'.

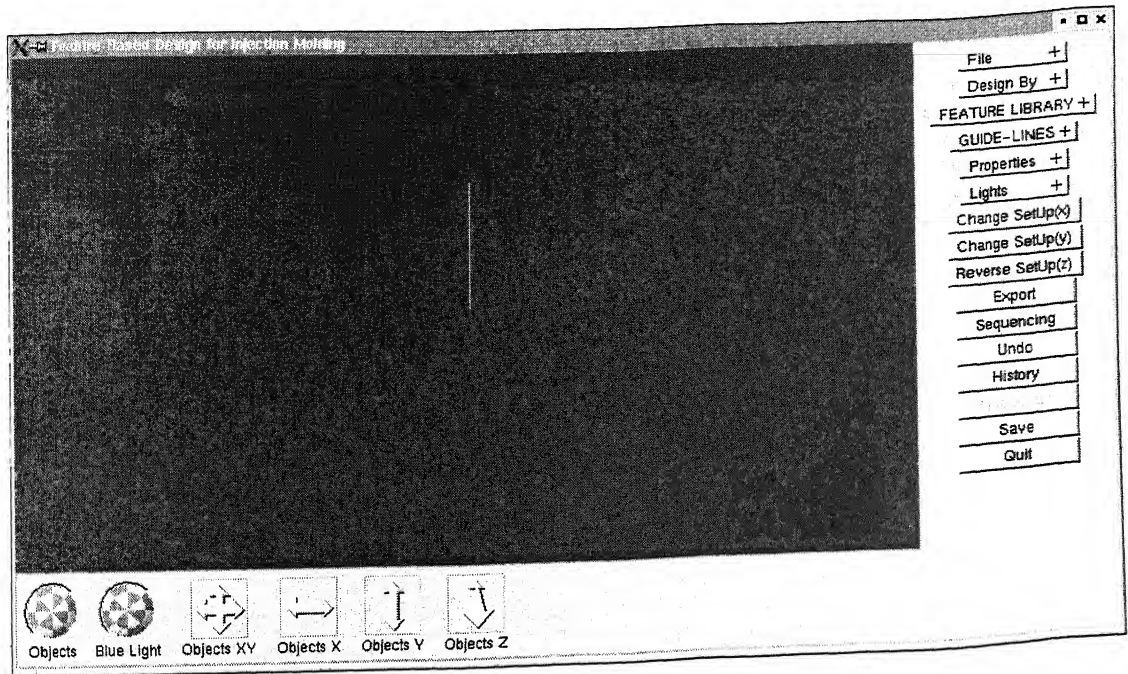
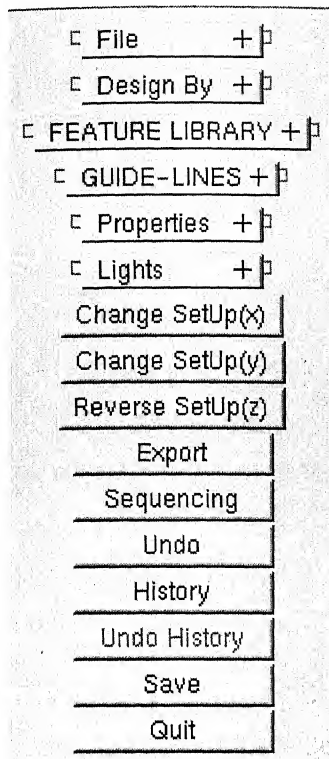


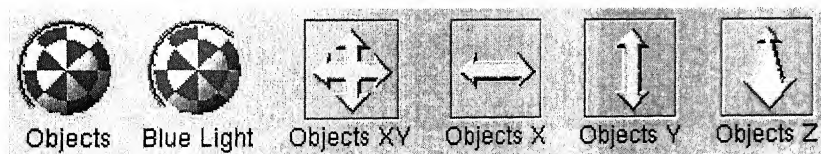
Fig. 4.8 Software Main Window

### Main Panel of the Software

Sub windows are used for displaying the control button on two panels. The left panel (figure 4.9) accommodates the database and library functions while bottom panel has object rotation, X Y Z translations and blue light rotation knobs (figure 4.10).



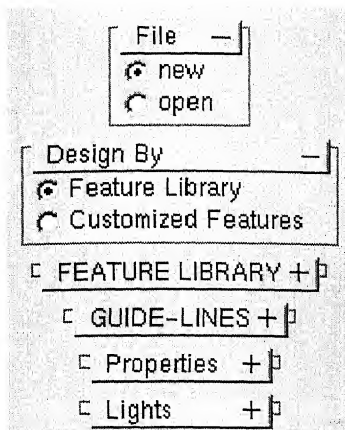
**Fig. 4.9- Side Control Panel**



**Fig. 4.10- Bottom Control Panel**

## Design Options

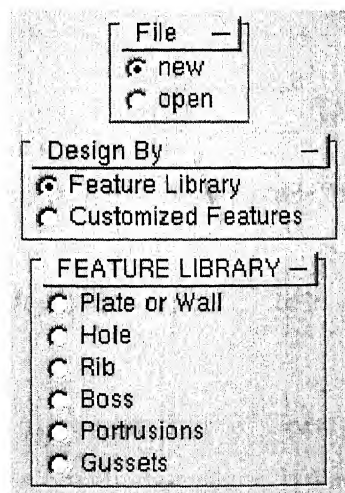
The system has options of designing the part with standard parameterized features extracted from feature library or defining own user defined features for custom plastic products.



**Fig. 4.11- Design Options**

## Feature Library

The feature library once selected will roll over the features available. The features can be selected with on/off selection of radio buttons. Six listed features are predefined and used as basic primitive for modeling. Features are extracted one by one and using rendering tools it is manipulated relative to each other to get the desired part shape. The parameters of features are evaluated on line and warning messages pops up if the geometry is prone to defected molding.

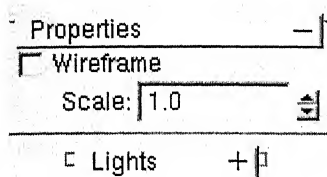


**Fig. 4.12- Features Available in Library**

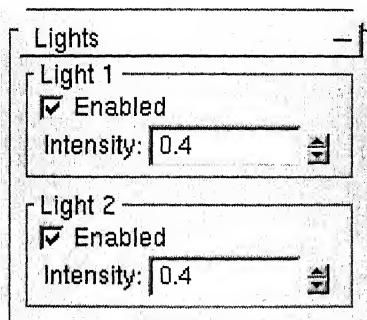
## Additional Facilities

The effect of lights and fog plays a very important role in any 3D solid modelling platform. Although OpenGL displays the object by creating low level entities such as points, triangles and quads, but the use of lighting parameters and fog effects make any displayed solid object a real perspective.

The wire frame display option and scale option also helps is better visualization of the object.



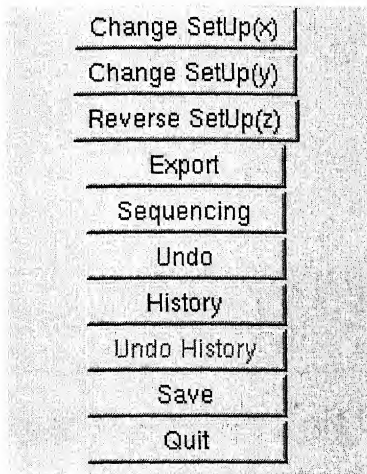
**Fig. 4.18- Wire Frame and Scale Menus**



**Fig. 4.19- Light Enable Menus**

## Common Facilities

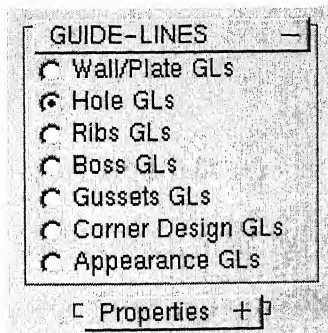
All the facilities of Open, Save, Quit, Undo are provided at bottom of the side panel. The setup change option is also tried to some extent.



**Fig. 4.20- Common Options**

## Design Guidelines

The design guidelines database presented in previous chapter is used as an in built expertise to judge the poor geometry of parts. These guidelines are also stored as reference manual and can be accessed by clicking on Design Guidelines rollout button as shown in figure 4.12.



**Fig. 4.13- Guidelines Manual**

The design Guidelines for individual features are stored together and can be referred as a manual online as shown in figure 4.12.

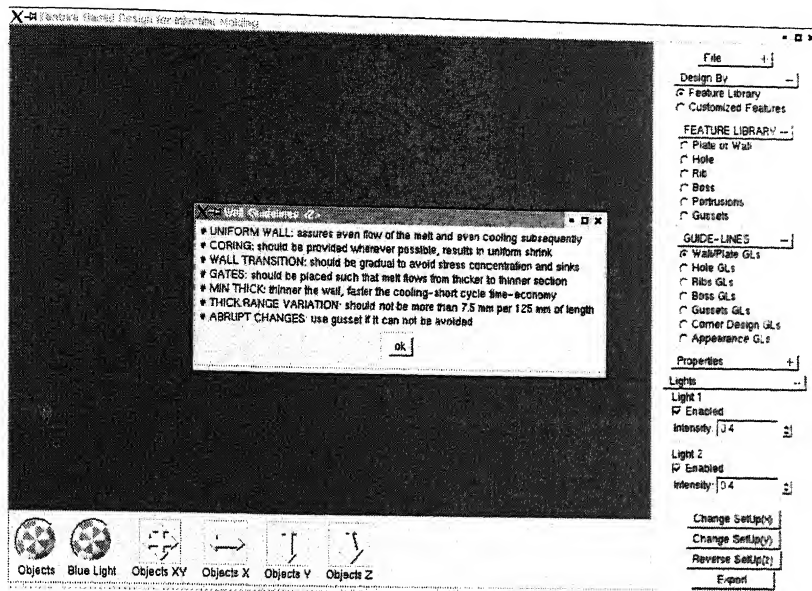


Fig. 4.17- Guideline Manual

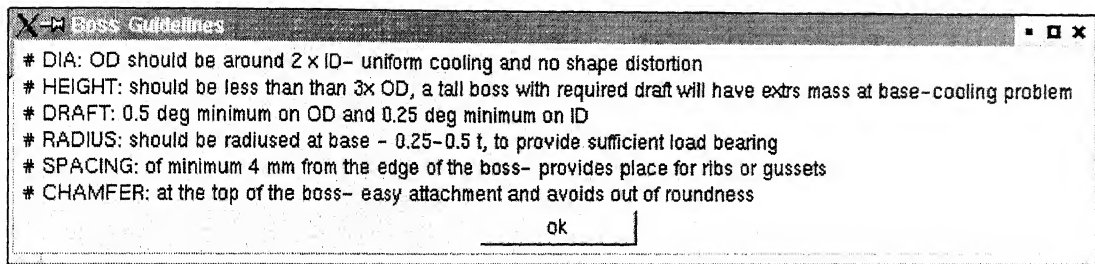


Fig. 4.18- Boss Guidelines Window

## 4.6 Case Study

The software display of individual feature creation and its rendering to get required shape of the plastic part is shown in following figures.

## Plate

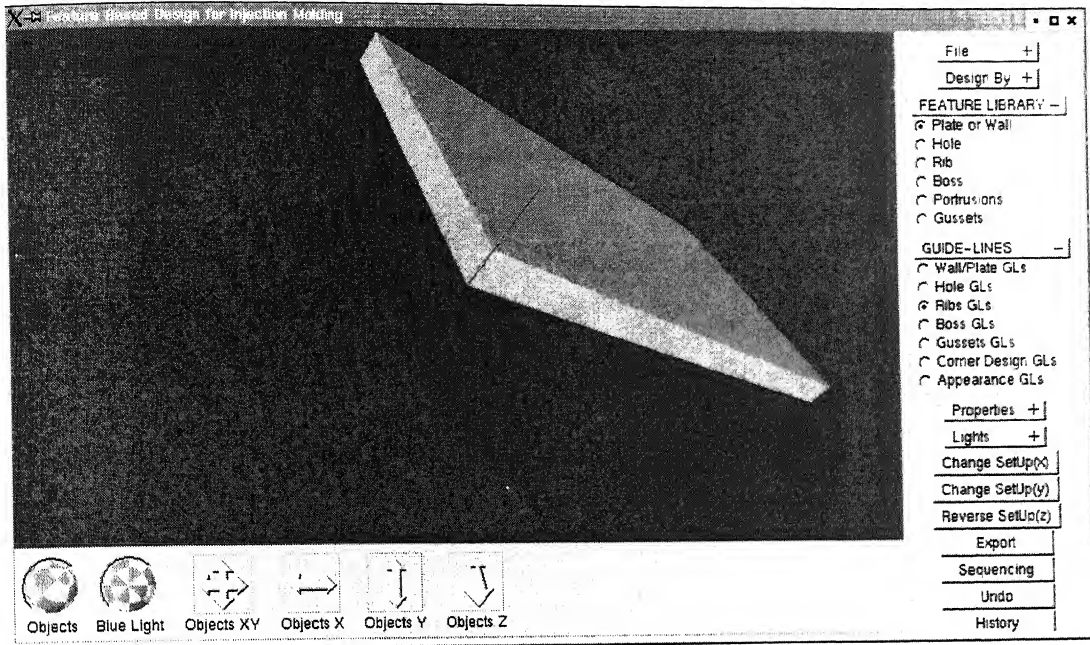


Fig. 4.19- Displayed Plate Feature

## Wall

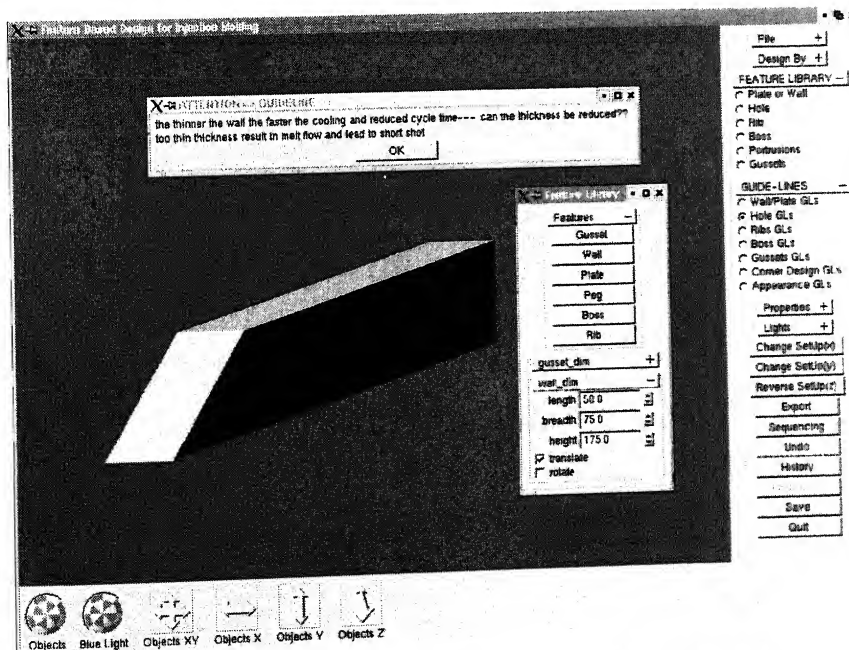


Fig. 4.20- Displayed Plate Feature with online Guidance

## Hole

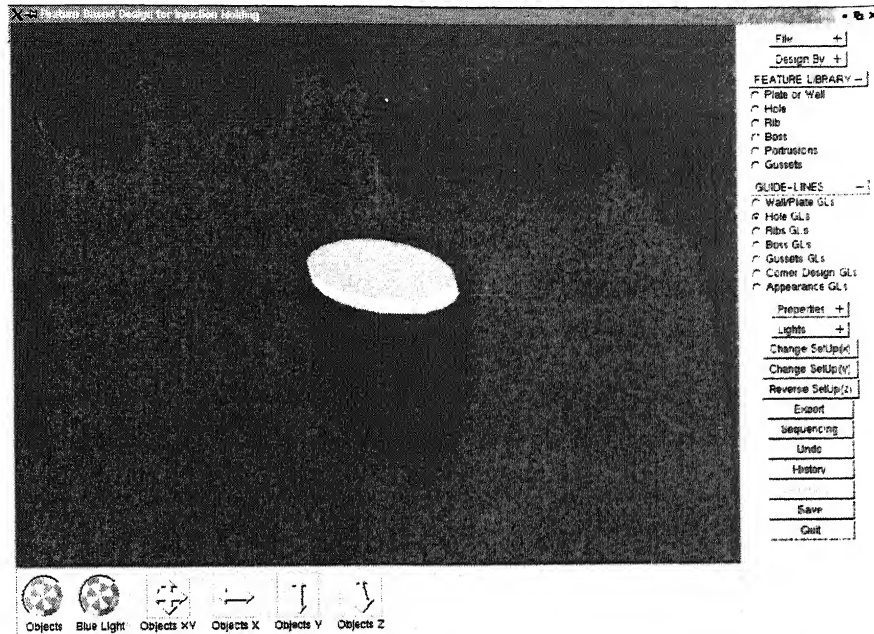


Fig. 4.21- Displayed Hole Feature as material to be removed

## Gusset

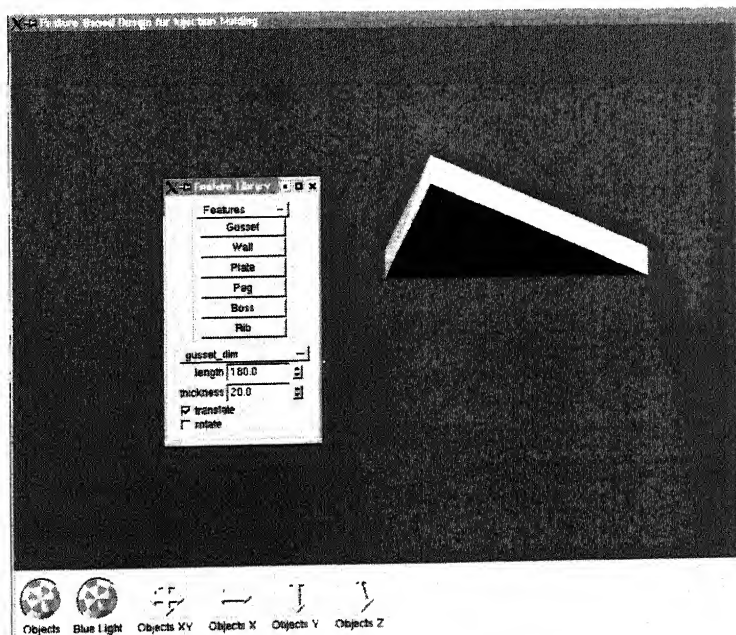


Fig. 4.22- Displayed Gusset Feature

## Ring

As all the features are parameterized, other new features can be created using the main features of the library. Figure 4.23 shows ring feature created using boss feature parameterization.

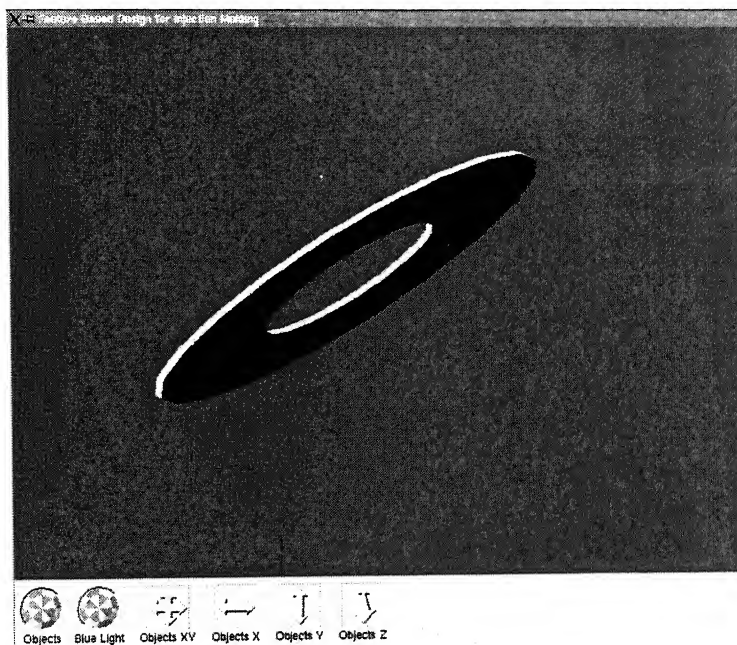


Fig. 4.23- Ring Feature

## Boss

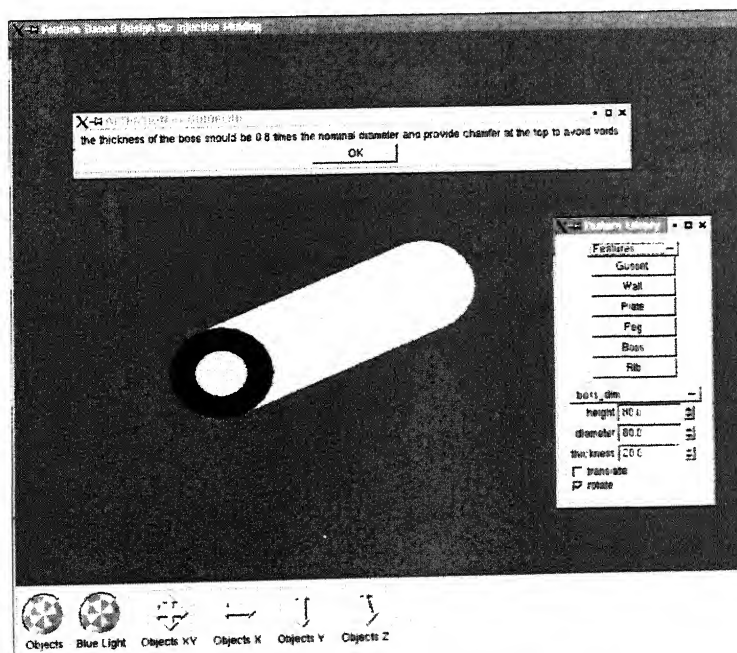
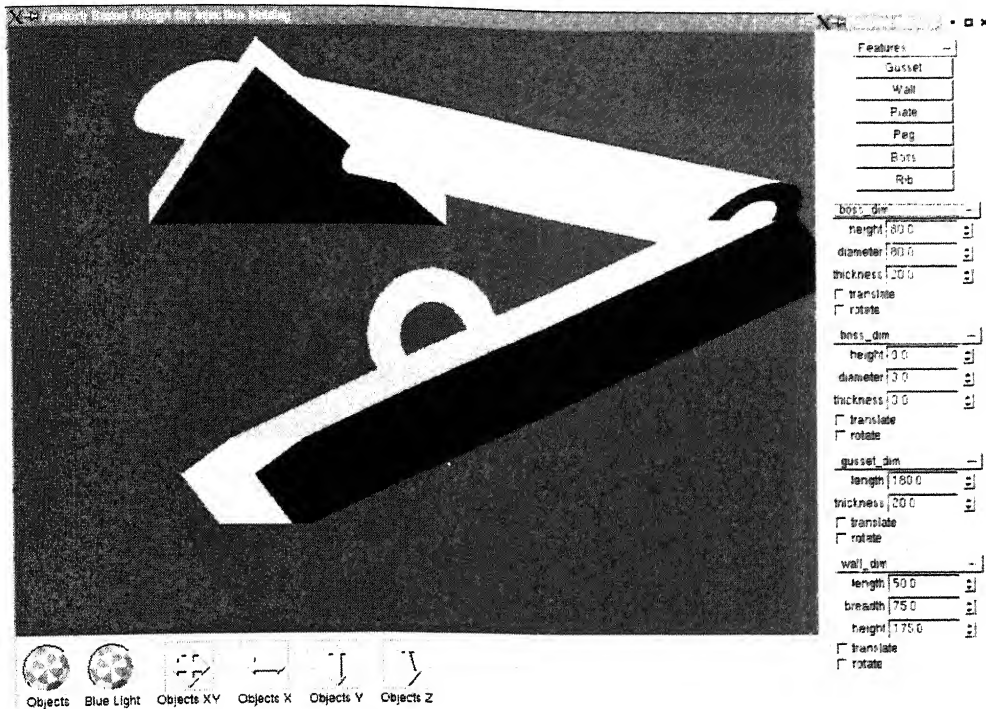


Fig. 4.24- Boss Feature with Guidelines

## Part Shape Generation



**Fig. 4.25- 3D Rendering of Features for Plastic Part**

## Dynamic Editing of Features

Features once created have the provision to edit its parameter any time during rendering. It is just required to click and modify the dimension window to get modified feature displayed on the screen. This dynamic editing option is very helpful when the feature dimensions interfere with each other. Figure 4.16 shows the user control over features.

#### 5.1 Conclusion

Object oriented feature based design system has come out to be an important tool in today's manufacturing and molding industries. It does not need complex feature recognition and mapping procedures for down stream CAM applications. It's easy adaptability with knowledge based systems have made it a versatile tool for development of integrated product design systems.

A software implementation for feature based design for injection molding has been tried in the present work. The use of high level form features, as modeling primitives makes the developed system suitable for a layman's design platform, where he can design optimized injection molded part geometry without any in depth process knowledge. The heuristic knowledge databases with standard guidelines are utilized as an expert system. This integration of feature-based design is a step towards the goal of having a better platform for design of parts for better moldability.

#### 5.2 Scope for Future Work

In the present work six common features viz. plate, boss, rib, gusset, protrusions and hole are created as member of the feature library. It can be extended further for many more unique features covering a wide range of injection molded plastic parts.

The present work of feature based design can be further explored as following

- Creating many more user defined features and allowing designing wide variety of parts.

- Data structure can be transferred in some neutral format such as IGES.
- The model data of the plastic part can be utilized for rapid prototyping of the molds using techniques such as laminated object manufacturing (LOM).
- FEM flow simulation algorithms can be combined to make it a complete integrated product design system.
- Dynamic editing of features can be made more user friendly

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